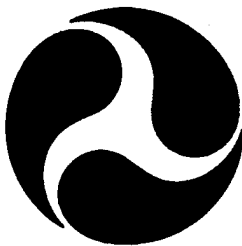


Report No. CG-D-02-96

Surface Flammability of Nonmetallic Pipes

**David W. Alley
Dr. William H. McLain
David E. Beene, Jr.**

**U.S. Coast Guard
Research and Development Center
1082 Shennecossett Road
Groton, CT 06340-6096**



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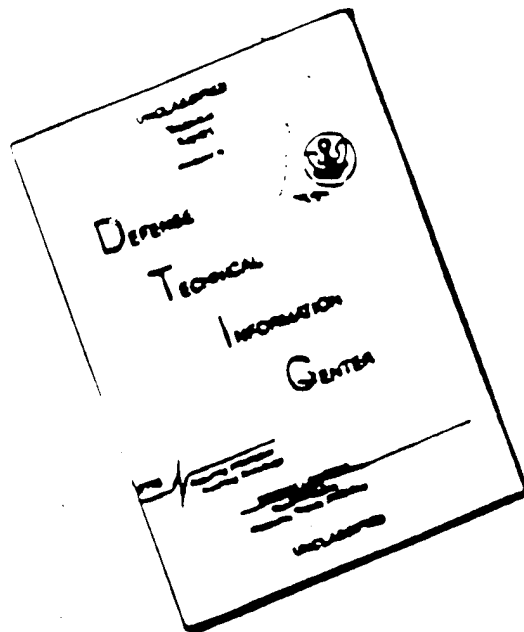
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G. T. Gunther

Technical Director, Acting
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1082 Shennecossett Road
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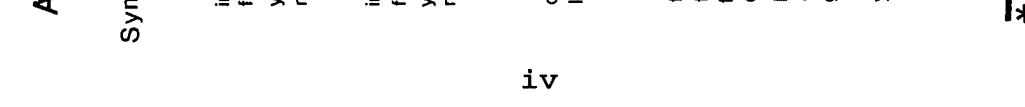
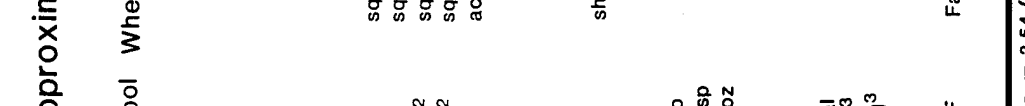
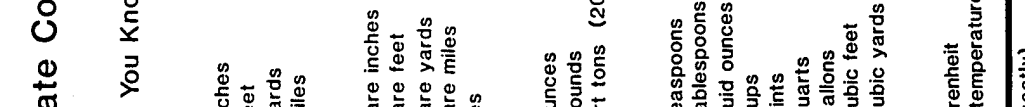
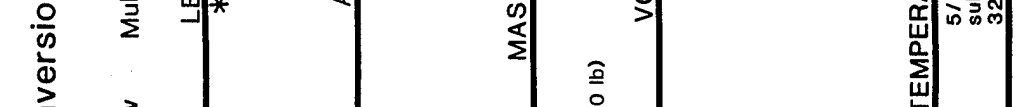
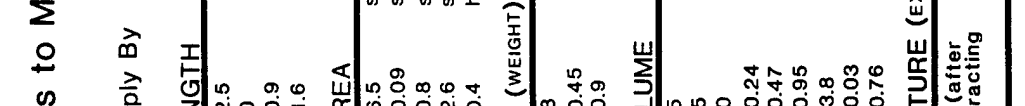
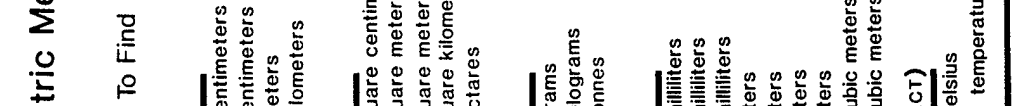
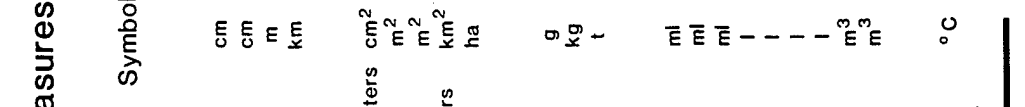
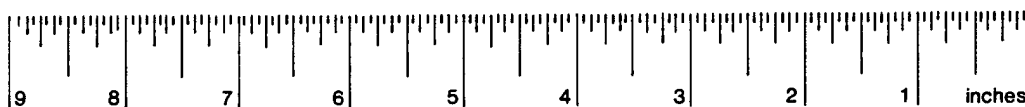
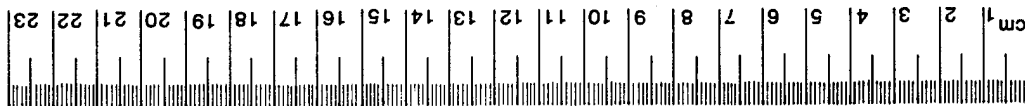
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16. Abstract There is currently no test designed specifically to test the spread of flame on nonmetallic piping. Such a test is required to meet the International Maritime Organization's requirements for use of nonmetallic pipe on board vessels. This work considers the suitability of two modified tests and their acceptance criteria for meeting this testing requirement. The two tests are (a) the IEC publication 332-3 (Flame Spread Test for Electric Cable) as modified by IMO FP 33/11/4 and (b) the Test for Surface Flammability for Bulkhead, Ceiling, and Deck Finish Materials, IMO Resolution A.653(16). Both tests were found to be executable. Data collected using the IEC test procedure was highly dependent on the test geometry. A method to "correct" this data to a set of standard conditions was developed. Theory predicts that data obtained from the IMO test procedure should also depend on test geometry. In most instances the data did not reflect this dependency. Several geometrically sensitive parameters were involved in each test. The effects of these parameters appear to be offsetting for the conditions tested.					
17. Key Words Flame spread, nonmetallic piping, fiberglass piping, IEC 332-3, IMO Resolution A.653(16), surface flammability			18. Distribution Statement This document is available through the National Technical Information Service, Springfield, VA 22161		
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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

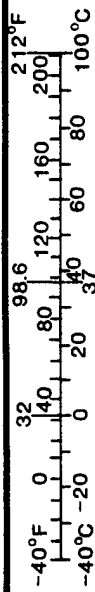
Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
in	inches	* 2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
AREA				
in ²	square inches	6.5	square centimeters	cm ²
ft ²	square feet	0.09	square meters	m ²
yd ²	square yards	0.8	square meters	m ²
mi ²	square miles	2.6	square kilometers	km ²
	acres	0.4	hectares	ha
MASS (WEIGHT)				
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
VOLUME				
tsp	teaspoons	5	milliliters	ml
tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft ³	cubic feet	0.03	cubic meters	m ³
yd ³	cubic yards	0.76	cubic meters	m ³
TEMPERATURE (EXACT)				
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly).



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH				
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
AREA				
cm ²	square centimeters	0.16	square inches	in ²
m ²	square meters	1.2	square yards	yd ²
km ²	square kilometers	0.4	square miles	mi ²
ha	hectares (10,000 m ²)	2.5	acres	
MASS (WEIGHT)				
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
VOLUME				
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	0.125	cups	c
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m ³	cubic meters	35	cubic feet	ft ³
m ³	cubic meters	1.3	cubic yards	yd ³
TEMPERATURE (EXACT)				
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



ACKNOWLEDGMENT

This work was originally begun in the late 1980's by Dr. William McLain and Mr. David Beene. It was originally intended for publication as more than one report. Work in this area was interrupted by the retirement of Dr. McLain. The data for this report then lay dormant for a period of several years. Mr. Louis Nash was invaluable to this effort in providing a historical link to the actual experimentation and data collection.

The authors express their appreciation to Ameron Fiberglass Pipe Division, Smith Fiberglass Inc., Ingalls Shipbuilding, and PPG Industries Incorporated for their cooperation and contribution of the vast quantity of piping and other materials which contributed significantly to the successful completion of this project. These companies were extremely generous and timely in supplying the piping and personnel training necessary to keep this project supplied with test materials.

The authors wish to acknowledge Ensign Kevin Frost and Lieutenant Commander Bob Diaz for their input and assistance while serving as project officers in the Marine Technical and Hazardous Materials Division.

The authors also wish to acknowledge the assistance provided by LCDR Caroline Foy and Ms. Bettie Proctor. They were instrumental in the preparation of graphics, data tables, and final editing. Their efforts greatly improved the quality of this report and reduced its preparation time.

Use of Units

The general convention used for reporting metric and English units in this investigation is to list the metric unit first and follow it by its approximate English equivalent (e.g., 50 mm (2-inches)). This convention is used except when the actual data was taken in English units. In cases where the actual data is English, the English unit is listed first and is followed by the approximate metric equivalent (e.g., 2-inches (50 mm)). English units are most commonly associated with nominal pipe diameters and pipe spacing.

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1.0 BACKGROUND

The movement toward the incorporation of "plastic" and organic matrix composite materials aboard vessels has been neither smooth nor easy. These materials offer considerable advantages to the marine industry in terms of cost, weight, resistance to corrosion, and flexibility of design. These advantages however, are not without liabilities.

Many of these liabilities are in the realm of fire safety. Plastics and organic matrix composite materials are substantially organic in nature and, as such, are subject to burning. While some will burn much more readily than others, all at least have the potential to burn. By contrast, the materials to be replaced by plastics and composites (generally steel) are inherently non-flammable.

The trade-offs between plastics, composites, and steel are particularly acute in terms of piping in accommodation and service spaces, particularly on passenger vessels. Vessel owners are more likely to install fixed fire suppression systems, such as sprinkler systems, if they are permitted to do so using plastic piping. Plastic piping is both lower in weight and installed cost when compared to its non-plastic counterparts. If it is assumed that a vessel owner will install a sprinkler system in an accommodation space, only if plastic piping is permitted, and if it is assumed that the sprinkler system performs as designed, the use of plastic piping on vessels will greatly increase the fire safety for property and personnel. On the other hand, should the fire suppression system malfunction, the plastic piping will increase the total fire load in the compartment, increase the rate at which flames spread through the compartment, increase the generation of smoke, and reduce the fire endurance of the pipe when compared with steel. All of these items reduce the fire safety of the space to levels below the original, non-sprinklered space.

With the intent of optimizing the trade-offs involved in plastic piping, the United States Coast Guard and the International Maritime Organization's (IMO) Subcommittee on Fire Protection have been considering the issues involved with plastic pipe since approximately 1988. The Coast Guard has published one report on this subject, titled "Fire Endurance Testing of Fiberglass Pipes" (1). A second report on smoke production from fiberglass pipes is in the process of being published. IMO has incorporated rules concerning flame spread (surface flammability of nonmetallic pipes) of plastic pipes in Regulations II-2/34.3 and 49.1 of the 1974 Convention for Safety of Life at Sea (SOLAS 74) as amended.

In the late 1980's and early 1990's there was considerable debate within the IMO's Subcommittee on Fire Protection concerning the adoption of a standard test method by which flame spread on plastic pipes could be measured. Two tests were considered. These were the IEC publication 332-3 "Tests on

Electric Cables Under Fire Conditions" (Appendix A) and IMO's Test for Surface Flammability of Bulkhead, Ceiling, and Deck Finish Materials, Resolution A.653(16) (Appendix C). Both of these test procedures required modifications to test pipes. The IEC procedure, originally designed to test electrical cable, was modified by FP 33/11/4 (Appendix B). The IMO procedure, originally designed to test only flat surfaces, was modified by the IMO Working Group for Fire Test Procedures, FP 35/WP.9, Annex (July 1990) (Appendix D).

2.0 OBJECTIVE

This study will use existing data to consider several questions concerning the use of the IEC and IMO test methods to determine flame spread on plastic pipes. These questions include:

- a. Can the test procedures be executed as prescribed by the test methods?
- b. Are the test results repeatable?
- c. Are the test results sensitive to extrinsic characteristics of the pipes tested, such as wall thickness or diameter?
- d. Are the original acceptance criteria (for wires and flat surfaces) appropriate acceptance criteria for pipes?

While it is always beneficial to continue the development and improvement of test methods, the results of this study may indicate how important it may be to develop a new flame spread test procedure.

3.0 MATERIALS

The data considered in this report were obtained from three test series conducted over a period of several years. The first two series (designated IEC and IMO1) were conducted to compare the test methods and to consider the sensitivity of the geometries used. The third test series (designated IMO2) was conducted to consider the realism of the IMO pass/fail criteria.

Table 3.1 is a matrix of materials and the tests in which they were used. Pipe sizes listed are nominal dimensions based on English units (inches). Metric equivalents are approximations. In all instances outside diameters exceed the nominal size. Inside diameters may be larger or smaller than the nominal diameter. Wall thicknesses of PVC pipe corresponds either exactly, or very closely, to the listed iron pipe size schedules. Wall thicknesses on the other types of pipes do not appear to correlate well with these schedules. Appendix E is a listing of manufacturers and additional specifications (where available) for the test pipes.

TABLE 3.1 Matrix of Materials and Tests

Material	Pipe Size (in) (mm)	Code	IEC	IM01	IM02
Polyvinyl Chloride	3/4 (19)	PVA1		X	
	2 (50)	PVA2	X	X	X
	2 (50)	PVA4	X	X	
	2 (50)	PVA6	X	X	
Chlorinated PVC	2 (50)	CPB2			X
	2 (50)	CPC2			X
	2 (50)	CPD2			X
Phenolic Fiberglass	2 (50)	PHE2	X	X	
	4 (100)	PHE4	X	X	
	6 (150)	PHE6	X	X	
Epoxy Fiberglass	2 (50)	EFF2	X		
	3 (75)	EFF3	X		
	4 (100)	EFF4	X	X	
	6 (150)	EFF6	X	X	
	2 (50)	EFG2	X		
	3 (75)	EFG3	X		
	4 (100)	EFG4	X	X	
	6 (150)	EFG6	X		
Vinylester Fiberglass	2 (50)	VEF2	X		
	4 (100)	VEF4	X	X	
	6 (150)	VEF6	X	X	
	2 (50)	VEG2	X		
	3 (75)	VEG3	X		
	4 (100)	VEG4	X	X	
	4 (150)	VEG6	X	X	

4.0 IEC 332-3 FLAME SPREAD TESTING

Fifty-nine modified IEC 332-3 flame-spread tests were conducted at the U.S. Coast Guard's Fire and Safety Test Detachment in Mobile, Alabama. The required test chamber was set up inside a cargo hold, on the test vessel MAYO LYKES, to prevent wind or rain from affecting the test results.

Polyvinyl chloride pipes (PVC) and three types of fiberglass pipes were tested (see Table 3.1). In addition to the modifications to the test method contained in FP 33/11/4, the Coast Guard also varied the separation between the samples. The standard 2-inch (51 mm) separation was used for most tests.

Separations of 1 inch (25 mm) and 3 inches (76 mm) were also investigated. A few tests were conducted using only one pipe instead of the two required by the test procedure.

4.1 Test Apparatus

The test apparatus was constructed in accordance with IEC 332-3 as modified (Appendices A and B). The following paragraphs contain a general description of the apparatus along with some details "as constructed."

The test chamber consists of a steel "box" having a width of 1 m, a depth of 2 m and a height of 4 m. The floor of the chamber was raised 150 mm above the ground level. The chamber has openings at the lower front (800 x 400 mm) and upper rear (300 x 1000 mm) for ventilation, but it is otherwise nominally air tight. The back and sides of the test chamber were thermally insulated with 65 mm of mineral wool. Also part of the test chamber was a steel "ladder" which functioned as a sample holder. This ladder was mounted within the test chamber at a distance of 150 mm from the rear wall.

Pipe samples were mounted on the front of the ladder using steel wire ties. As previously stated, the separation distance between the pipes was normally 2 inches (51 mm), although distances of 1 and 3 inches (25 and 76 mm) were also used. As will be seen in the data analysis, this dimension was critical to the results of the test.

The ignition source was a pre-mixed, ribbon-type, propane gas burner whose flame-producing surface consisted of a flat plate 341 mm long and 30 mm wide through which 242 holes 1.32 mm in diameter were drilled. During these experiments the air flow to the burner was $4.6 \pm 0.28 \text{ m}^3/\text{h}$ ($163 \pm 10 \text{ ft}^3/\text{h}$). The fuel flow rate was adjusted, based on the energy content of the fuel, such that the energy input to the burner was $73.7 \pm 1.68 \times 10^6 \text{ J/h}$ ($70,000 \pm 1600 \text{ Btu/h}$).

The burner was positioned such that the long axis of the burner plate was oriented horizontally, and the short axis was oriented vertically. This orientation directed the flames horizontally towards the pipes. The distance between the burner plate and the front surface of the test samples was 75 mm. The burner flame impacted the pipes 500 mm above their lower ends.

4.2 Instrumentation

When used as a "production" test, the test method requires only limited data to be taken. For the purpose of studying the test method, additional parameters were measured. These parameters included ambient conditions (outside the test enclosure), flame temperature, air temperature inside the test chamber, wall temperature inside the chamber, burner flame temperature, sample temperature, air flow velocity into and out

of test chamber, air flow velocity above test chamber, propane and air flow rate to burner and oxygen, and carbon monoxide and carbon dioxide concentrations inside the chamber. Some of these values were measured only to ensure that they remained constant. During the data analysis, the remaining values did not appear to provide significant insight into the results. They will not be considered further in this report.

Video cameras and photographic equipment were used to document the test setup, procedures, and results. A composite videotape was assembled to show all aspects of the testing.

Instrumentation and video equipment were calibrated daily during this test series.

4.3 Procedures

The tests were conducted in accordance with IEC 332-3 as modified (Appendices A and B). The following paragraphs contain a general description of the tests:

In general terms, the test method requires samples to be environmentally conditioned, and then immediately placed in the test chamber and tested. In this test series, the samples were conditioned in a chamber at 23 ± 5 degrees C (73 ± 9 degrees F) for a period of three hours, and then immediately moved into the test chamber (which was at the same temperature). In order to prevent any flames from entering the bottom of the pipe, a metal cup (51 mm height, appropriate diameter) was placed over the bottom of the pipe. The top of the pipe was left open to prevent pressurization.

Once the samples were installed, the burner was ignited and the samples were allowed to burn. Each test concluded when the sample failed to ignite, self extinguished, or charred to its full height. At the end of the test, the burner was extinguished and the charred length was measured. Char heights were measured vertically upward from the bottom of the burner (not the bottom of the pipe).

4.4 Results

Tabular results are contained in Appendix F. Test numbers containing the letter (a) were conducted in August 1988 and the others were conducted in June 1989. Comparisons must not be made between tests containing the (a) suffix and other tests. Two pipes were used in most tests. The distance between pipes (not center to center) is listed in the table. Tests in which only one (1) pipe was used are indicated by "--" in the column headed "Distance Between Pipes". This table lists maximum char heights and indicates whether the samples passed the IEC 332-3 performance requirement.

4.5 Discussion

4.5.1 Executability

The procedures set forth in Appendices A and B were, in general, executable and reasonable. Two difficulties were encountered, both involving the measurement process.

The first difficulty involved determining the exact height to which the sample was charred. Even after wiping away the soot which collected on the pipes, the location of the end of charring could not always be precisely determined. This undoubtedly adversely affected the repeatability of the results.

The second problem involved the locations at which the char height measurements were to be taken. The test procedure stipulated that the height of the char was to be measured at the front and rear of each sample. During the first few tests (designated by the suffix (a) in the test number) it became apparent that this was not sufficient to obtain the maximum height. In later tests the height of the char was measured at the front, rear, right, and left of each sample. The maximum value obtained was the value used. Since char heights measured where the two pipes were closest together were often much higher than either front or rear measurements, data from tests with the (a) suffix may NOT be compared to tests without the suffix.

4.5.2 Repeatability

Any discussion of the repeatability of data obtained by this method must be viewed with some degree of skepticism. Of the 54 tests for which valid data were obtained, there were 13 replicate data pairs. Of those 13 pairs, 6 pairs were charred to their full height, and are therefore meaningless in discussing data repeatability. Information on the variability of the data for the remaining 7 data pairs is contained in Table 4.1. Although the repeatability shown in Table 4.1 is very impressive for this type of test, it must be stressed that it is based on very limited data.

4.5.3 Sensitivity to Extrinsic Characteristics

Figure 4.1 shows that for small diameter pipe, e.g., 2-inch (50 mm), this test method is capable of differentiating the flame spread characteristics of the test materials based on their intrinsic properties (i.e., the material of which they were made). Figure 4.1 shows with equal clarity that the test method is very sensitive to pipe diameter.

Table 4.1 Variability of Data

Test No.	Char Height (m)	Average (m)	Difference (m)	Percent Difference
7 27	1.88 1.55	1.72	.16	9.3
9 29	1.12 .86	.99	.13	13.1
18 38	.71 .74	.72	.02	2.8
39 19	1.42 1.04	1.23	.19	15.4
15 35	.25 .38	.32	.07	21.9
16 36	.31 .43	.37	.06	16.2
17 37	.48 .43	.46	.03	6.5

Average Percent Difference: 12.2

Figure 4.2 shows that char height is also very sensitive to the spacing between the pipes. While the test method, as prescribed, is very sensitive to both pipe diameter and spacing, it should be theoretically possible to correct for these variables. This theoretical correction is developed in the following paragraphs.

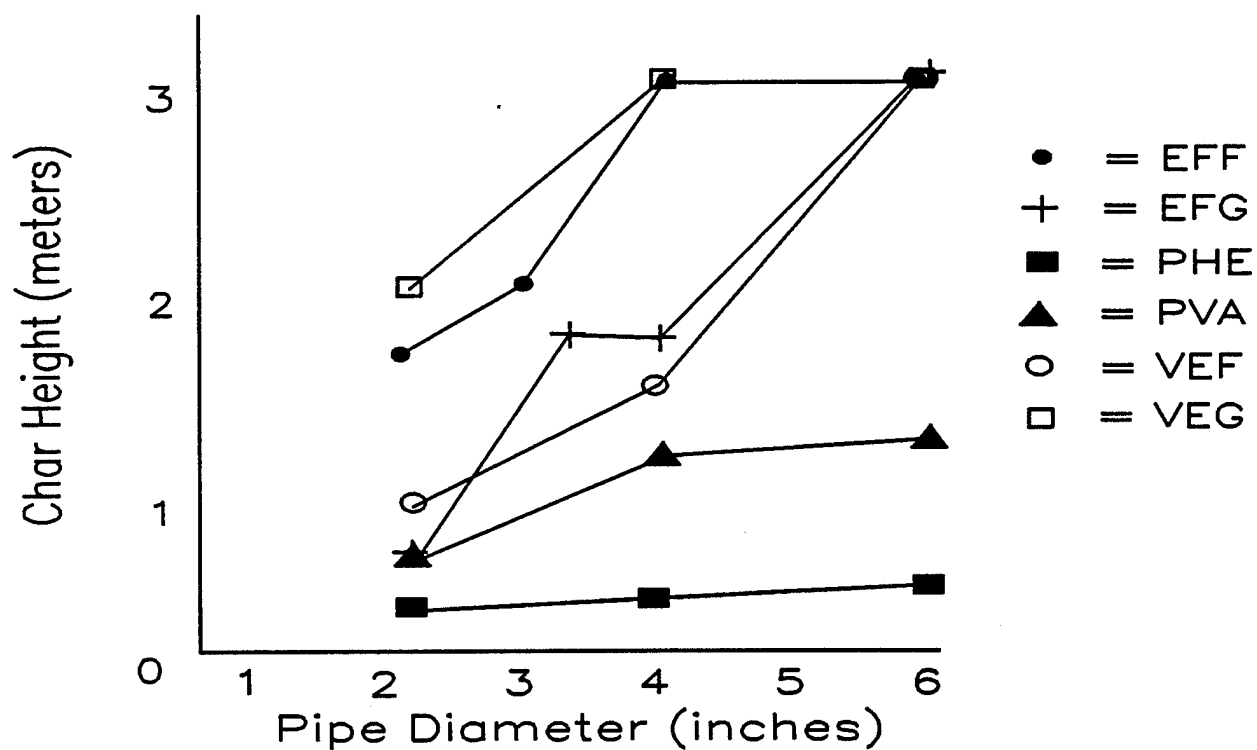


Figure 4.1 Effect of Pipe Diameter on Char Height

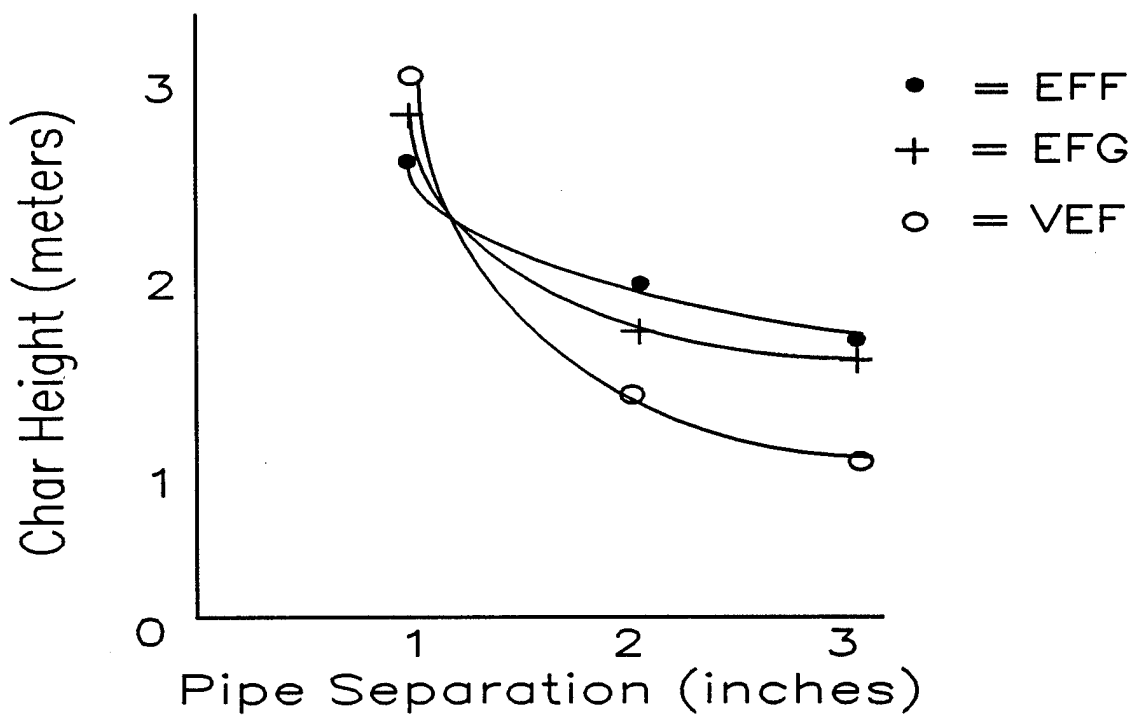


Figure 4.2 Effect of Pipe Separation on Char Height

Radiant heat flux to the pipe comes from three primary sources: the burner, the other pipe (if present), and the back wall of the enclosure. Given these three sources of radiant energy, theory predicts that: burning will tend to stop as it progresses away from the burner; burning will progress further for large pipes mounted close together, and in the absence of a second pipe, burning should not progress as far as when a pair of pipes is used. These theoretical predictions are in good agreement with actual observations.

In the area close to the burner, it is apparent that the burner is the most important source of energy. The burner was able to light all the samples and cause them to burn for at least a short distance. At greater distances, energy from the second pipe becomes very important; pipe pairs burned at least twice as far as a similar single pipe. The effect of energy from the back wall is not immediately obvious from the data.

The relative contributions of energy from "the other pipe" and from the back wall depend on two factors, the temperature of the radiating surface, and the view factor between the surfaces. The surface temperature is very critical since the radiant energy transmitted is proportional to T^4 . This would indicate that the contribution of the back wall is not likely to be significant (because its temperature is much lower than the burning pipe), unless its view factor is much greater than the pipe to pipe view factor.

The view factor between two parallel pipes of infinite length is:

$$F_{1-2} = [(X^2 - 1)^{-0.5} + \sin^{-1}(1/X) - X] / \pi \quad \text{Equation 4.1}$$

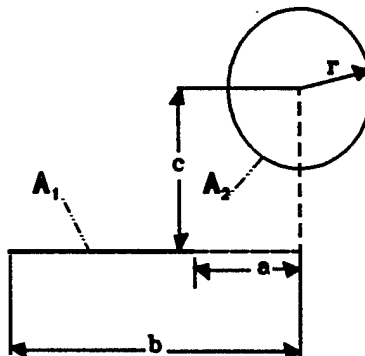
Where: $X = 1 + S/D$

S = Distance between pipes

D = Outside diameter of pipe

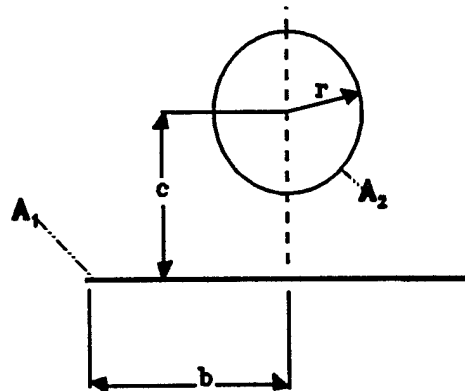
The view factor between a plate of finite width and infinite length and a parallel cylinder is:

$$F_{1-2} = [r/(b-a)] * [\tan^{-1}(b/c) - \tan^{-1}(a/c)] \quad \text{Equation 4.2}$$



In this case, since $a = 0$ and since the plate extends in both directions from the centerline of the cylinder, the view factor equation reduces to:

$$F_{1-2} = 2r/b * [\tan^{-1}(b/c)] \quad \text{Equation 4.3}$$



For nominal pipe diameters of 2 - 6 inches (50 - 150 mm), pipe separations of 2 inches (51 mm) and a pipe to wall separation of 150 mm, the pipe to pipe view factors range from 0.09 to 0.13. The wall to pipe view factors range from 0.148 to 0.381.

The fact that the wall to pipe and pipe to pipe view factors are similar, and that the burning pipe temperature is much higher than the back wall temperature, indicates that the radiant energy transmitted from the back wall is not significant when compared with pipe to pipe transmission. This position is supported by the available data. For single pipe tests, if the back wall contributes significant energy, the char height should increase with pipe diameter. This comparison is possible for three types of pipes. Within the precision of the data, char height is not a function of pipe diameter for any pipe type. As a result, the contribution of radiant energy from the back wall will not be considered further in this analysis.

The use of these view factors is actually not justified from a theoretical point of view. In both cases the view factor assumes an infinite length of plate or pipe. Since burning occurs in only a short length of the pipe at any given time, the temperature gradient along the pipe will give rise to "end effects" which are not strictly accounted for in these view factors. While this could cause some degree of inaccuracy in the analysis, it is not apparent given the scatter in the data.

Given the above assumptions and analysis, the following equation was developed to correct for pipe diameter and spacing.

The reference diameter and spacing were normally both selected to be 2 inches to make the best use of available replicate data. In one case, EFG pipe, the reference diameter was selected to be 4 inches and the spacing 2 inches for the same reason.

$$C_c = C_x * (V_2/V_x)^k \quad \text{Equation 4.4}$$

Where: C_c = The corrected char height
 C_x = Actual char height for test to be corrected
 V_x = View factor of test to be corrected
 V_2 = View factor for 2 in dia., 51 mm spacing
 k = Empirical constant

This equation was applied to all of the tests which involved two pipes and which had actual char heights of less than 3.05 meters. (A char height of 3.05 meters represented charring on the entire height of the sample. It is unknown how high the charring would have gone if the pipe was taller, therefore, it is not possible to scale these tests.) The percent difference between each corrected char height and the reference char height was then calculated.

$$\% \text{ Diff} = \frac{\text{Ref char ht} - \text{Cor char ht}}{\text{Ref char ht}} \times 100 \quad \text{Equation 4.5}$$

The average and standard deviation for all of the percent differences were then calculated. Being an empirical constant, k was adjusted to minimize these values.

For a k of 1.3 the mean percent difference was found to be - 0.012. The standard deviation of the percent difference values was 18.388. Ideally, in a perfect system, both of these values would have been precisely 0. Given that the repeatability of identical tests averaged about 12%, the standard deviation of 18% indicates that the char height correction equation explains nearly all of variation in char height attributable to diameter and spacing.

Tabular information concerning corrected char heights and percent differences is contained in Appendix G. The percent difference information is graphically represented in Figures 4.3 and 4.4. Note that there is no functional relationship between percent difference and either diameter or spacing.

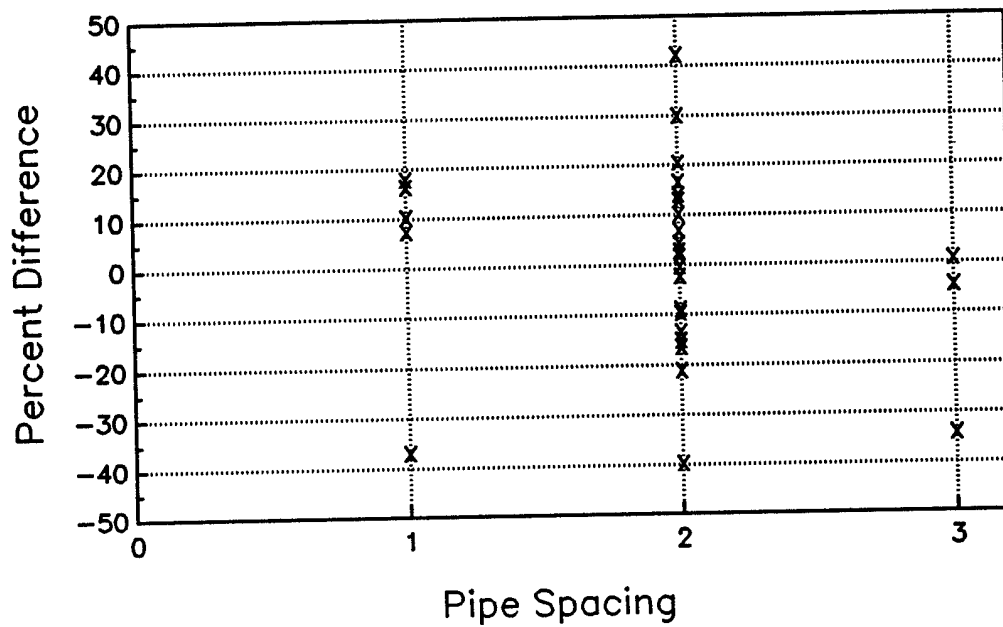


Figure 4.3 Percent Difference vs Pipe Spacing

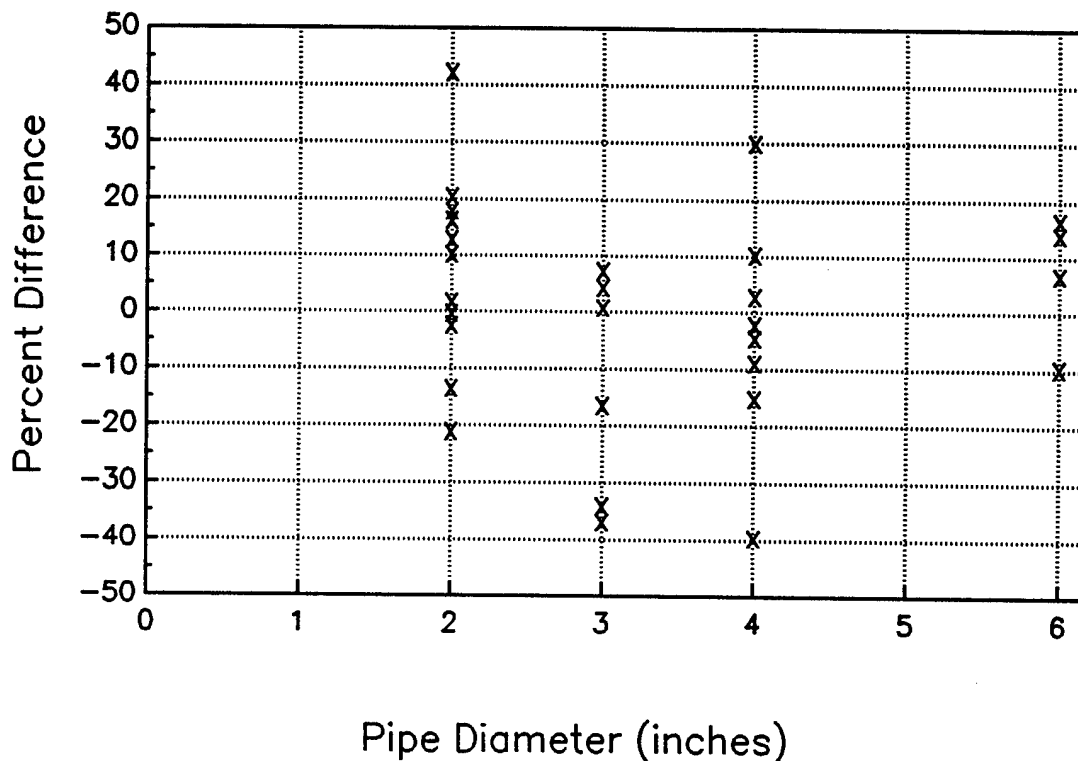


Figure 4.4 Percent Difference vs Pipe Diameter (inches)

4.5.4 Acceptance Criteria

The current acceptance criteria (accept if char height is less than 2.5 m) needs further definition if it is to be meaningful. Given the great dependence of the results of the test on the number of pipes, pipe diameter, and pipe spacing, it is not realistic to expect this test to measure the "safety" of actual installations. It is realistic to use this test to compare the "safety" of MATERIALS which may be used in actual installations.

It would be appropriate to establish an acceptance criteria of "Char height not to exceed x meters at a reference diameter of y and a reference spacing of 2 inches". The determination of x should involve additional testing, which would include both materials which are known to perform acceptably and those which are not acceptable. Testing could be conducted with one (any) diameter pipe. The results would then be corrected to the reference diameter and spacing to determine whether the MATERIAL passed or failed the test.

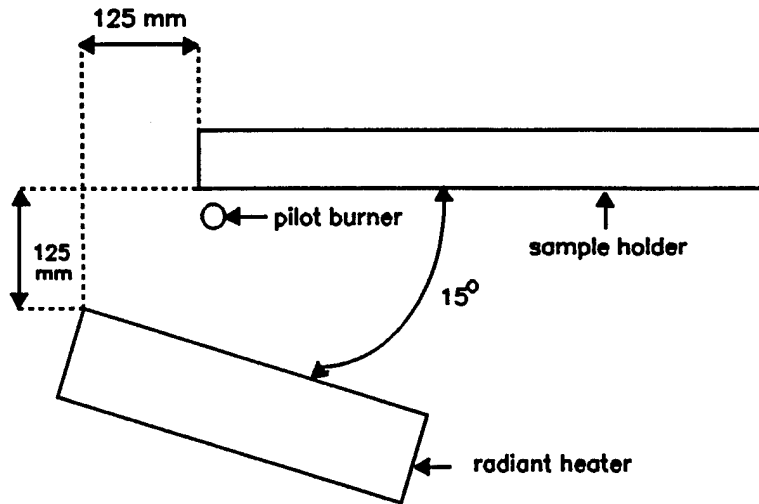
5.0 IMO RESOLUTION A.653(16) FLAME SPREAD TESTING

Two test series were conducted using modified versions of IMO Res. A.653(16). The first of these series tested a variety of pipe materials, diameters, and configurations. The primary purpose of this series was to test the viability of the test procedures used. The second series tested various types of 2-inch (50 mm) PVC pipe. The primary purpose of this series was to consider the reasonableness of proposed acceptance criteria. These tests were conducted at the National Institute for Standards and Technology, Gaithersburg, Maryland.

5.1 Test Apparatus

The test apparatus was constructed in accordance with IMO Res. A.564(16) as modified (Appendices C and D). The following paragraphs contain a general description of the apparatus:

The apparatus consists of four basic components: the radiant heater, the sample holder, the pilot burner, and the fume stack (Figures 5.1 and 5.2). The radiant heater is fired by premixed natural gas burners and is 280 mm x 483 mm. When installed, the major axis is oriented horizontally and the minor axis is oriented vertically. When operating, the radiant energy is projected in a horizontal direction. The sample holder is approximately 155 mm x 800 mm. When installed, the major axis is oriented horizontally and the minor axis is oriented vertically. When bolted together, the radiant heater and the sample holder are about 125 mm apart at the left end (when viewed from behind the heater), and further apart at the right end. The angle of divergence between the heater and the sample holder is 15°. The pilot burner is located just below the lower left hand corner of the sample holder. This burner projects a flame vertically, along the left edge of the sample. The closest approach between the flame and the sample is about 10 mm. The purpose of this burner is to ignite combustible gases generated by the radiant heater. The fume stack is located directly over the sample holder. It is sized to be able to collect all the exhaust gases given off by the burning sample.



Top View of Sample Holder and Radiant Heater

Figure 5.1 Sample Holder Top View

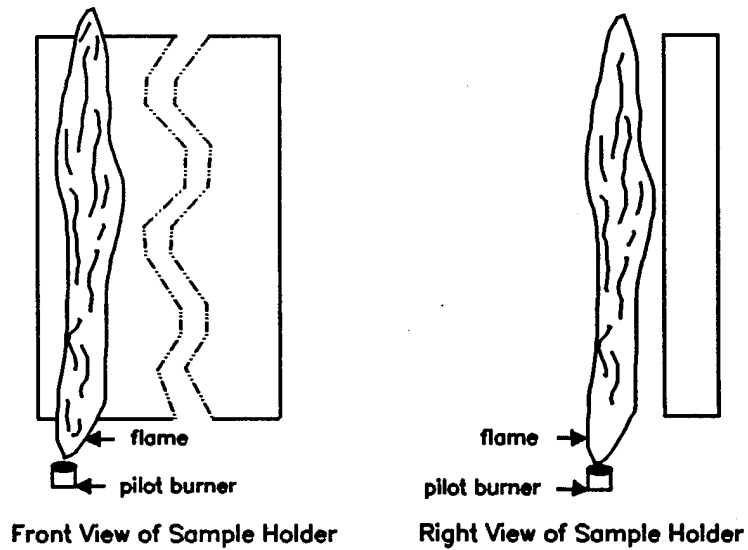


Figure 5.2 Front/Right Views of Sample Holder

5.2 Modifications

Substantial modifications to the test apparatus and procedures described in IMO Resolution A.564(16) are required to conduct tests on pipe material. These modifications are prescribed in Appendix D. An overview of the problems and the rationale for the selected modifications are provided below.

Sample Size - When testing flat material, the final sample size can be made to conform precisely to the sample size requirement in the test procedure. When testing pipe material, sample size will normally vary from that prescribed. While it is theoretically possible to section pipe material so that it covers the backing precisely (projected area), in practice this is not realistic. Due to difficulties in machining some of the pipe samples, it is necessary to limit samples to whole pipe sections, halves, and quarters, etc. All sectioning cuts must be made in a radial direction. These restrictions preclude an exact match between the size of the sample and the backing. High temperature ceramic wool is used to insulate, and hopefully "normalize" mismatches in sample size.

Sample Attachment - The procedures for affixing flat test samples to the backing include a variety of adhesive materials and direct application. These methods are not suitable for applying whole or sectioned pipes to the backing. 18 gauge nichrome wire wrapped around the pipe and passed through holes in the backing at 2-inch (50 mm) intervals is relatively easy to install and produces satisfactory results.

Thermal Contact Between Sample and Backing - The procedures for testing flat material require that the test sample make good thermal contact with the backing. This is important since many of the materials to be tested are thermally thin. The curvature of the pipe sections precludes good direct thermal contact with the backing. Thermal contact with the backing could be simulated by filling the cavity behind the pipe section with refractory cement. This is not deemed necessary because the pipe sections are thermally thick and because the test is somewhat more severe with lower thermal contact.

Sample, Radiant Panel Separation Distance - When testing flat materials, the separation distance between the sample and the radiant panel as well as the angle of divergence between the two is fixed. As a result, the energy flux reaching any point on a vertical line on the sample is equal. The flux decreases from left to right across the sample. When testing pipe, the flux reaching the samples varies both vertically and from left to right. The vertical variation in flux is caused by the changing distance between

the radiant panel and the sample surface. The variation in separation distance is due to the curvature of the pipe. The distance between the radiant panel and the sample is selected so that the highest point on the pipe surface is equal to the distance to the flat surface prescribed in the IMO Resolution. At this distance, along any vertical line, the peak flux reaching the pipe will equal the average flux reaching the flat surface.

View Factor - When testing flat surfaces, essentially all the incident energy comes from the radiant panel. When testing pipes, incident energy comes both from the radiant panel and from the surface of adjacent pipe sections. The relative importance of these sources is determined by the temperatures of the radiating surfaces and the view factors between them. No adjustment to the apparatus or procedures contained in the IMO resolution has or can readily be made to correct for this discrepancy.

5.3 Instrumentation

The instrumentation for this test method includes thermocouples and a fluxmeter. Visual data collection is also required. The exact instrumentation requirements may be found in Appendix D. The calibration of the radiant panel with the fluxmeter, to ensure that its output is constant in both space and time, is critical to the outcome of the tests. The measurement of the total and peak heat release are dependent on the calibration of the exhaust stack. The design of this stack has been criticized in the past as being insufficient to collect all of the combustion products. This criticism, while potentially valid, is of little concern because if there are sufficient combustion products to "overload" the exhaust stack, the test sample will clearly not meet the acceptance criteria.

5.4 Procedures

The exact procedures for testing are contained in Appendices C and D. Appendix C requires (and defines) that the following data be collected during the conduct of the experiment:

Critical Flux at Extinguishment - A flux level at the specimen surface corresponding to the distance of farthest advance and subsequent self-extinguishment of the flame on the centerline of a burning specimen. The flux reported is based on calibration tests with a dummy specimen.

Heat for Ignition - The product of the time from initial specimen exposure until the flame front reaches the 150 mm position and the flux level at this position; this latter obtained in prior calibration of the apparatus.

Heat Release of Specimen - The observed heat release under the variable flux field imposed on the specimen and measured as defined by the test method.

Heat for Sustained Burning - The product of time from initial specimen exposure until arrival of the flame front and the incident flux level at that same location as measured with a dummy specimen during calibration. The longest time used in this calculation should correspond to flame arrival at a station at least 30 mm prior to the position of furthest flame propagation on the centerline of the specimen.

5.5 Results

The results for the IMO Resolution A.564(16) test may be found in Appendix H. Results are identified by the type of material and manufacturer (see Appendix E), by pipe diameter, and by the number of segments into which the pipe was cut. Pipe diameter and number of segments are indicated by a 6 character code. The first character in the code is "D", indicating diameter. This is followed by the diameter in inches. The third character is an "S", indicating the number of segments. This is followed a digit indicating the number of segments into which the pipe was cut. A "1" in this place indicates that the pipe was left uncut. The fifth character is a "/" which is followed by a number indicating the number of segments actually used in a test. For example, the code D4S4/2 would indicate a 4-inch diameter pipe which was cut into 4 segments. Two of these segments would be used in the test.

5.6 Discussion

5.6.1 Executability

The process of modifying this test method to accept the testing of non-flat surfaces proved to be quite involved. Most of these problems were discussed in the "Modifications" section, above. Even after these modifications were adopted, there were still difficulties encountered in the conduct of these tests. The most notable difficulties involved measuring the spread of the flame, determining the weight loss, and dealing with the variations in sample widths.

The measurement of the spread of the flame along the surface of the sample was done by comparing elapsed time, as measured on a stopwatch, and distance, as determined by eye with the aid of "station" wires. While there are inherent inaccuracies in such a measurement system, they were of far less concern than the fact that the flame front did not spread evenly down the length of the sample. The flame front was observed to "stall" and "jump" at various times during its progress. The flame front was also very non-uniform along the vertical face of

the sample. While one might expect the flame to spread with equal rates at the top and bottom of the sample, or for the top to proceed slightly faster, there was no consistency to this behavior.

The determination of weight loss, although not part of the currently proposed acceptance criteria, proved difficult and prone to error. In many samples, pieces of the test material would fall off the backing material. To the extent possible, these pieces were recovered and weighed with the remainder of the sample. This problem will generally cause weight loss to be overstated.

Although the process for dealing with variations in sample width is executable as described, it does present difficulties both in terms of theory and the physical process of sample preparation. The major theoretical difficulty involves the use of extensive properties such as total heat release and peak heat release rate as acceptance criteria when sample size is allowed to vary considerably. Sample preparation for different size samples presents a problem because each sample must be considered and prepared individually. This requires extra preparation time and will adversely affect the repeatability of the data.

5.6.2 Repeatability

If, as theory would indicate, it is assumed that the measured values are functions of pipe diameter and the number of sections into which the pipe is cut, tests for each sample type contained 2 - 4 repetitions. The repeatability of the data varied from excellent (standard deviations approximately 5% of the measured values) to extremely poor (standard deviations in excess of 60% of the measured value). While there was some tendency for numerically small measured values to have higher standard deviations as a percentage of those values, this trend was not very significant. Some of the poorest repeatability occurred on "mid range" measured data.

The repeatability of the data was definitely a function of the parameter being measured. The repeatability of data for total heat released and peak heat release rate were better than the repeatability of data for heat of sustained burning and critical flux at extinction. The repeatability of data also appears to be a function of the material being tested. Standard deviations are, in general, lower for materials EFF, VEF, and VEG than they are for PVA and PHE.

5.6.3 Sensitivity to Extrinsic Characteristics

Theory indicates that all the measured parameters should be functions of one or more of the following:

Sample Area
Sample Thickness
Sample Height Above Backing
Sample Curvature

Since all of these items are functions of pipe diameter and the number of sections into which the pipe is cut, it would, at least initially, appear that the measured parameters should be functions of pipe diameter and the number of sections. Closer examination indicates that the functional relationship between pipe diameter, pipe segments and the measured parameters may be very complex. Figures 5.3 through 5.7 show the variability of the measured parameters (Q_t , q_p , CFE, Q_{sb} (described below)) as a function of pipe material, diameter, and spacing.

5.6.3.1 Total Heat Release, Q_t

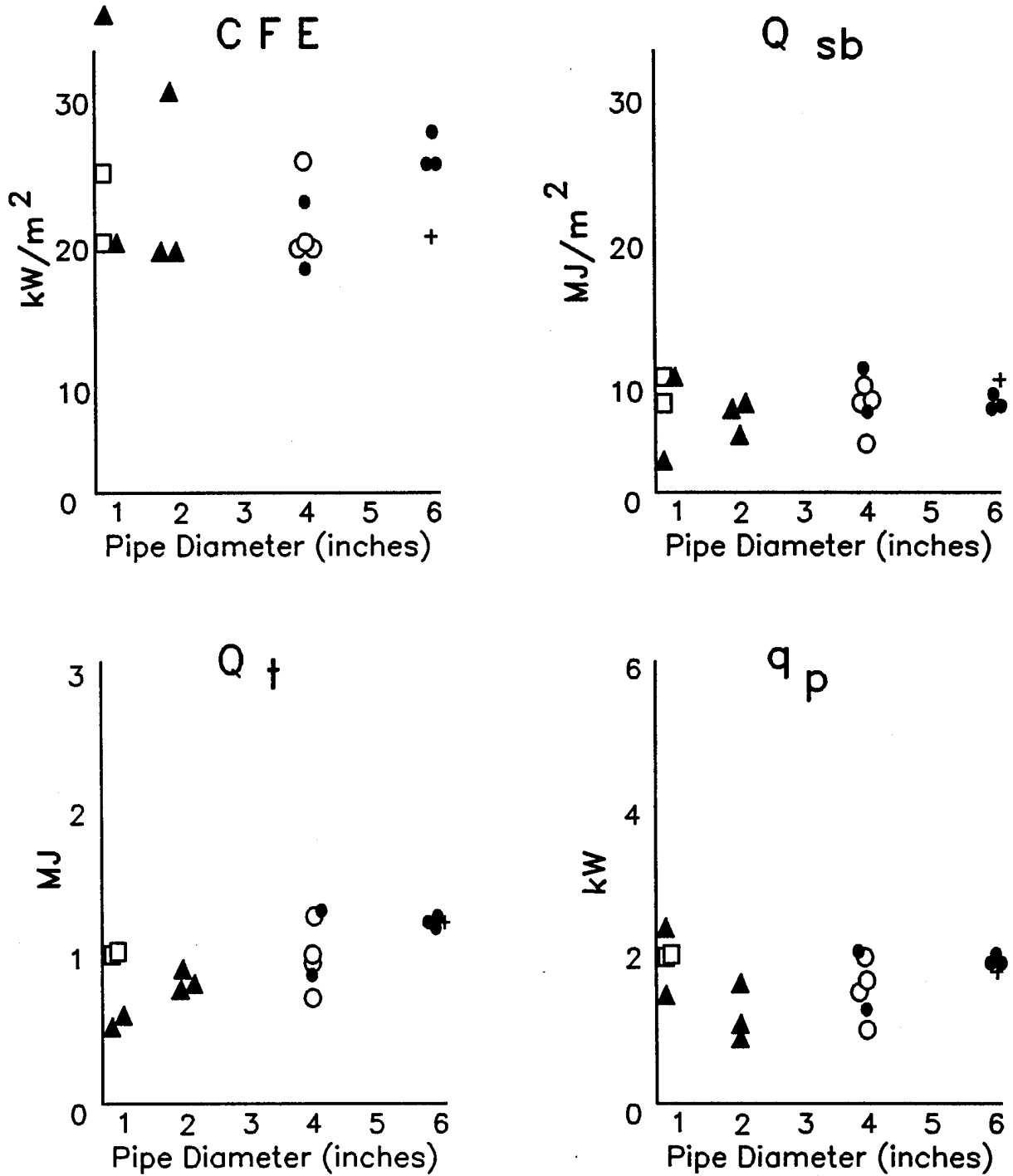
To a first approximation, Q_t of a sample should be a function of the total mass of material within the area of the sample which receives sufficient radiant energy to burn. This is, in turn, a function of the required energy for burning (a material property), the linear surface length, and the thickness of the material. Since linear surface length does not vary significantly and is not related to diameter, any correlation between Q_t and linear surface length will be difficult to find. Pipe thickness, on the other hand is strongly dependent on diameter for PVA pipe and weakly dependent on diameter for other pipes. Based on thickness, Q_t should increase with increasing diameter for PVA and vary only slightly for other materials.

In general, the data support the above theoretical relationships. Q_t does increase with increasing pipe diameter, although not as strongly as might be expected. Q_t does not appear to depend on diameter for PHE, EFF, or VEF. VEG^t presents an interesting problem in that Q_t appears to be negatively correlated with diameter. It is presumed that this is due to randomness in the data.

5.6.3.2 Peak Heat Release Rate, q_p

q_p should depend on the horizontal length of the sample which is burning at any given time, the linear surface, and the average radiant energy received on any vertical line drawn along the surface of the sample. The amount of a sample which is burning at any given time depends on the combustion characteristics of the material, an intrinsic property. The linear surface and the average radiant energy are loosely, inversely related. Assuming that the projected area of the samples is identical, which is not precisely true, a long linear surface requires a large maximum distance between the backing and the highest point on the sample. A large maximum distance will result in a lower average radiant energy reaching

PVA



of Segments: □=1 ▲=2 ○=4 ●=6 +=9

Figure 5.3 Measured Parameters as a Function of Pipe Diameter and Spacing for PVA

P H E

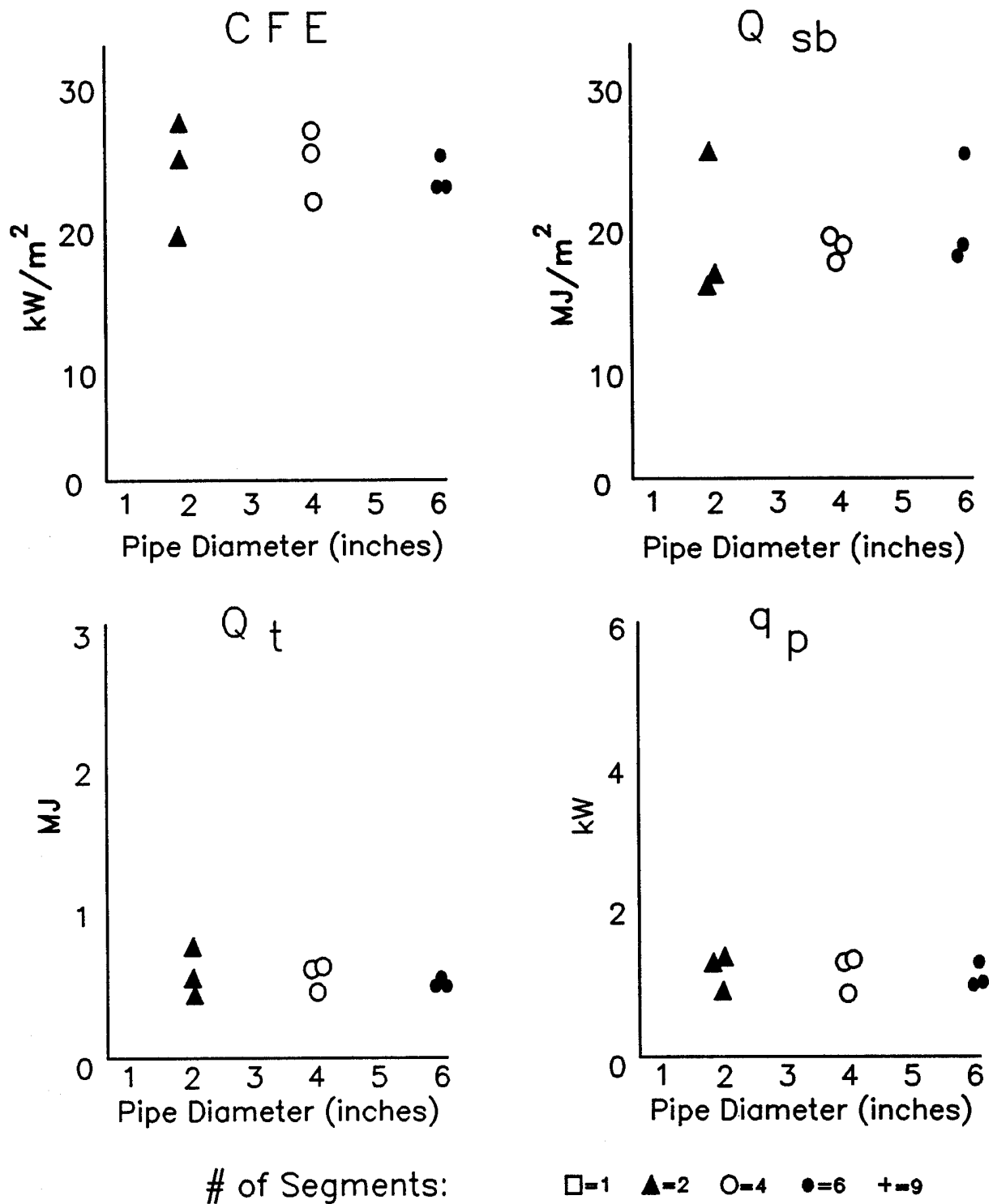
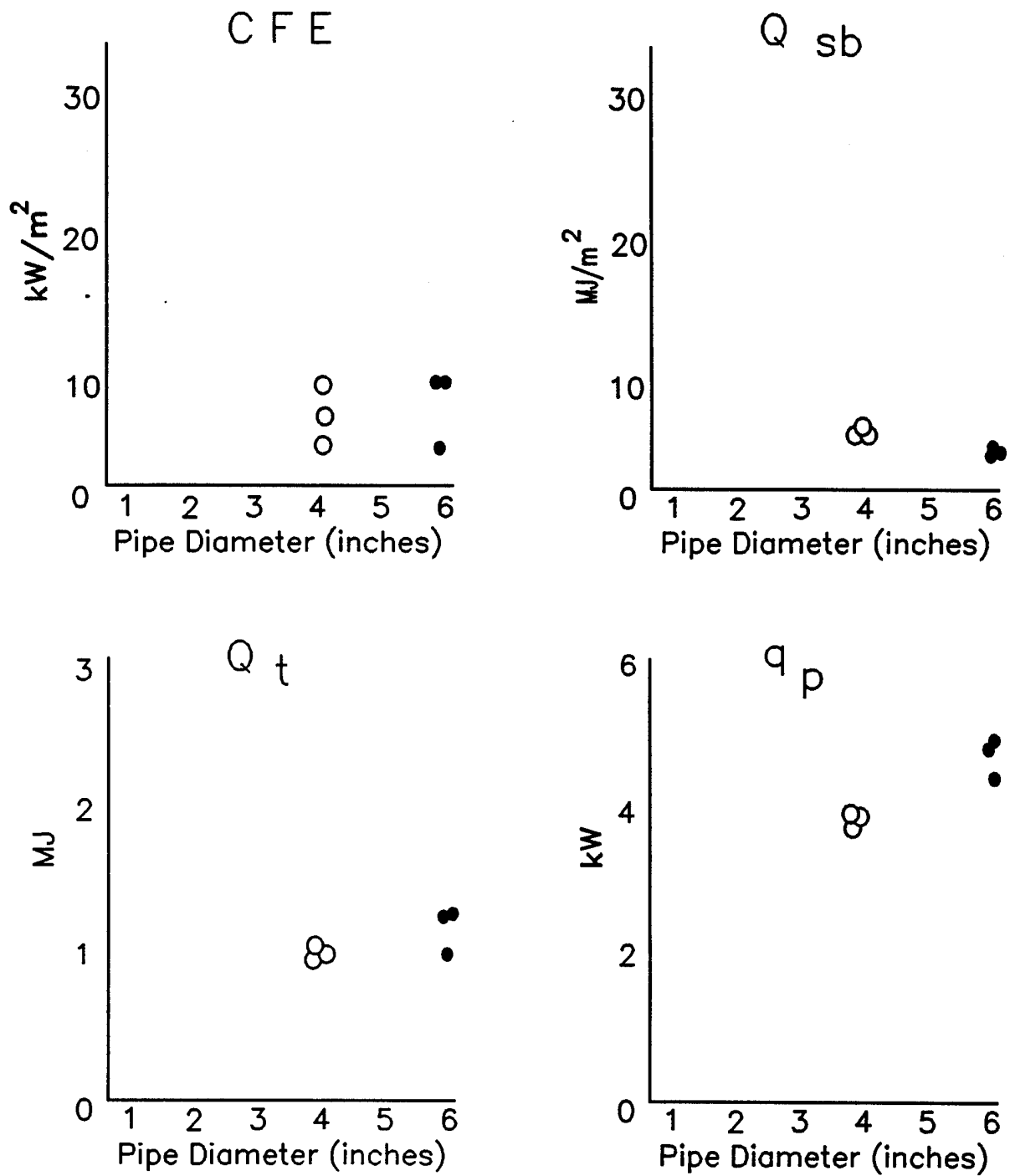


Figure 5.4 Measured Parameters as a Function of Pipe Diameter and Spacing for PHE

EFF

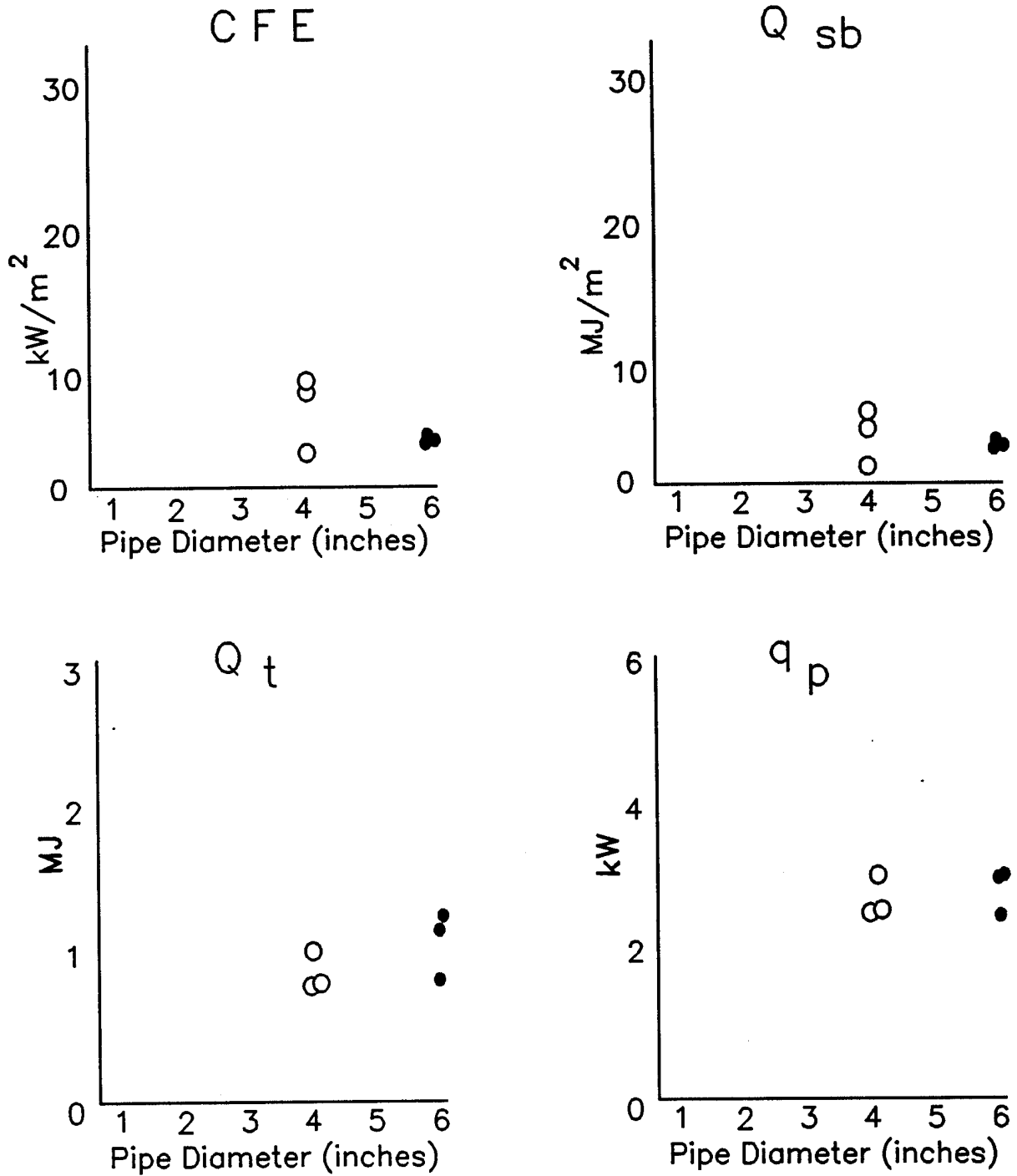


of Segments:

□=1 ▲=2 O=4 ●=6 +=9

Figure 5.5 Measured Parameters as a Function of Pipe Diameter and Spacing for EFF

VEF



of Segments: $\square=1$ $\triangle=2$ $\circ=4$ $\bullet=6$ $+=9$
 Figure 5.6 Measured Parameters as a Function of Pipe Diameter and Spacing for VEF

VEG

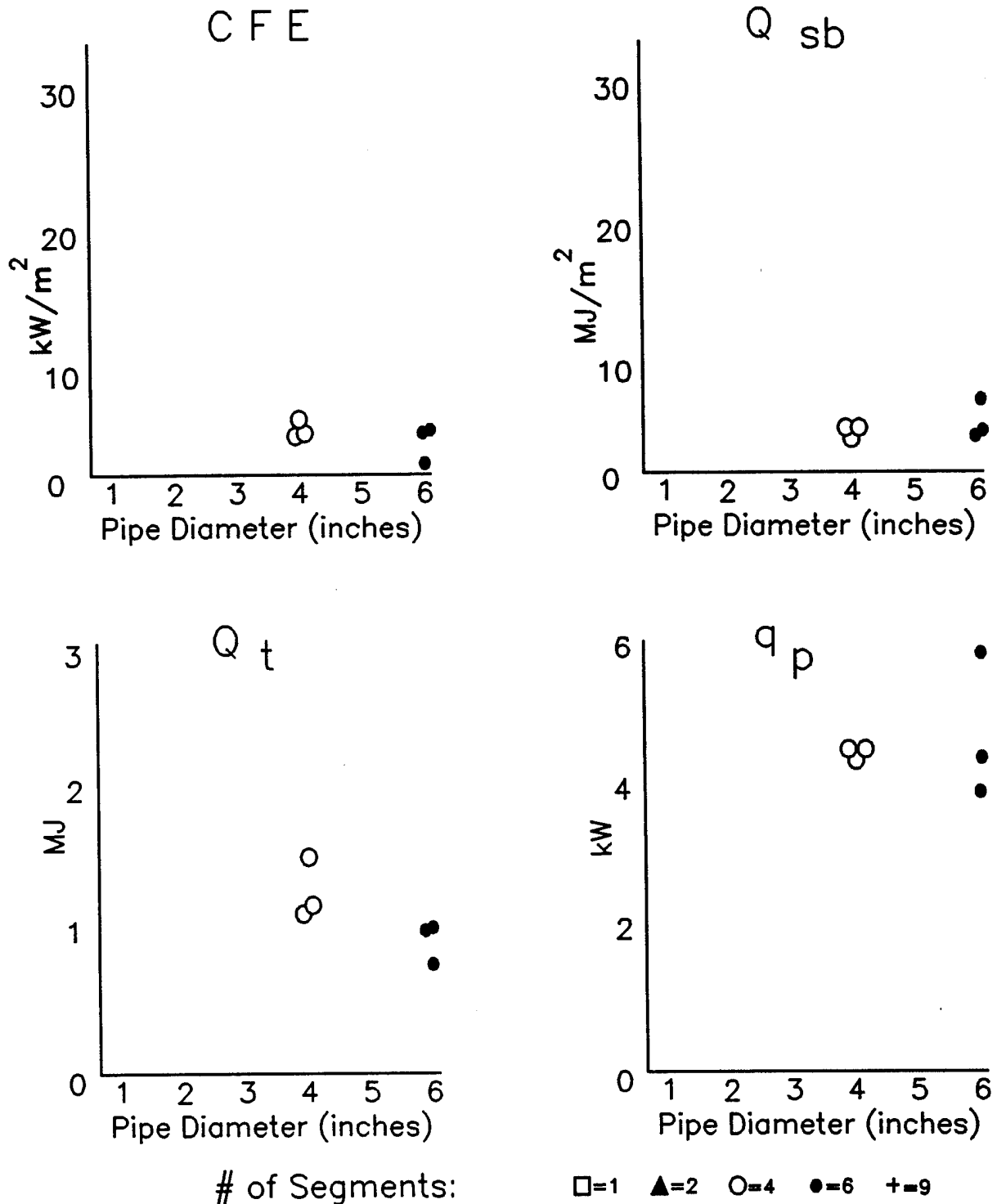


Figure 5.7 Measured Parameters as a Function of Pipe Diameter and Spacing for VEG

the sample. Based on this loose, non-linear, inverse relationship, it is not possible to predict the exact dependence of q_p on diameter.

The data for PHE, VEF, and VEG show no functional relationship between q_p and pipe diameter. EFF shows a positive correlation. PVA shows that q_p goes through a minimum for pipes of 2-inch (50 mm) diameter. Significant weight must be given to the PVA results since they represent the most complete data set.

5.6.3.3 Critical Flux at Extinction, CFE, and Heat of Sustained Burning, Q_{sb}

The values obtained for CFE and Q_{sb} should be related to the average heat flux and the view factor between adjacent pipes. As was mentioned above, large distances between the backing and the highest point on the sample result in low average heat fluxes. Conversely, large distances between the backing and the highest point on the sample result in high view factors between adjacent pipe samples. While a sophisticated analysis of the magnitudes of these effects could be conducted, it is doubtful that the predictions of such an analysis would be of sufficient accuracy to justify the effort unless convective effects as well as radiative effects due to incandescent smoke particles were included. To include these effects would require further experimentation.

The data clearly show that view factors and/or convective effects are important in determining Q_{sb} and CFE. Three tests were run with 3/4-inch (19 mm) pipe in which one segment, two segments spaced 10 mm apart, and two segments spaced 15 mm apart were used (Appendix H). The radiant heater was not able to produce flaming on any of these specimens. For larger samples, it appears that variations in the average heat flux and the view factors are roughly offsetting. Within the reliability of the data, which is less than desirable in some cases, CFE and Q_{sb} appear to be unrelated to pipe diameter.

5.6.4 Acceptance Criteria

The currently proposed acceptance criteria for this test are:

$$\begin{aligned} Q_t &= <0.7 \text{ MJ} \\ q_p &= <4.0 \text{ kW} \\ Q_{sb} &= >1.5 \text{ MJ} \\ CFE &= >20.0 \text{ kW/m}^2 \end{aligned}$$

These criteria were developed for thermally thin wall coverings. Thermally thin wall coverings bear no resemblance to thermally thick pipe material. The testing of thermally thin wall coverings is also not complicated by the theoretical concerns associated with the testing of curved surfaces. As a

result there is no reason to retain these acceptance values for pipes unless they properly differentiate between acceptable and unacceptable materials (based on fire history).

The proposed acceptance criteria also appear deficient in that they do not adequately address the scatter in the data. Especially for Q_{sb} and CFE, any set of acceptance criteria need to have a statistical component.

Although it is not the objective of this study to determine the desirability of the values of the acceptance criteria (as opposed to their validity), if it is assumed that none of the criteria are functions of pipe diameter (a very questionable assumption), and if all the values for a particular pipe type are averaged, very few pipe materials will meet the proposed criteria (Table 5.1).

Table 5.1 IMO Res. A.653(16), Results

TEST MATERIAL (units)	Q_t MJ	q_p kW	Q_{sb} MJ	CFE kW/m ²
PVA	<u>1.0*</u>	1.7	8.52	23.2
CPB	<u>0.8</u>	0.8	33.0	<u>12.5</u>
CPC	0.6	0.7	39.0	29.4
CPD	0.5	0.7	49.0	32.2
PHE	0.6	1.2	20.9	25.0
EFF	<u>1.0</u>	3.9	4.6	<u>7.3</u>
EFG	0.6	<u>5.1</u>	4.3	<u>14.3</u>
VEF	<u>0.9</u>	2.9	4.3	<u>7.6</u>
VEG	<u>1.3</u>	<u>4.8</u>	4.3	<u>4.9</u>

* Underlined Values Fail To Meet Proposed Acceptance Criteria

While this may be appropriate from a fire safety standpoint, it will limit the available material choices. It would appear desirable to test additional materials which are known to be both "good" and "bad" to further refine the appropriate acceptance values.

6.0 CONCLUSIONS

A) The IEC test procedure, as modified, was executable. One further modification to the procedure is required. The existing procedure calls for measuring the char height at the front and the back of the pipe. Since the maximum char height is normally on the side facing the "other" pipe, char heights should be measured at the front, rear, left, and right. The maximum value measured should be used.

B) The data obtained using the IEC test procedure did not contain as many replicate tests as would have been desirable. The repeatability of the data was acceptable for this type of test. Greater confidence in the results of this test could be obtained by requiring a statistically significant number of samples and including statistical significance in the acceptance criteria.

C) The results of the IEC test procedure are dependent on the geometry of the test (pipe diameter and pipe separation) to a greater extent than they are on the material being tested. If repeatable data are to be obtained using this test method, the test procedure must be very stringent concerning variability in the test geometry.

D) The geometrical variability in the IEC test data is due largely, if not wholly to differences in the view factor between the pipes. The equation

$$C_c = C_x * (V_2/V_x)^k \quad \text{Equation 4.4}$$

Where: C_c = The corrected char height
 C_x = Actual char height for test to be corrected
 V_x = View factor of test to be corrected
 V_2 = View factor for 2-inch dia., 51 mm spacing
 k = Empirical constant

where k is 1.3, will correct char heights obtained using various pipe diameters and spacings to a reference diameter and spacing of 2 inches. The above equation can be readily modified to select a different reference diameter should that be desired.

E) Further consideration of the 2.5 m char height acceptance criteria is required. At present this criteria does not adequately address either the "as installed" performance of plastic piping or the performance of the pipe material. If it is desired to limit the flame spread on installed plastic piping to 2.5 m (or some other chosen value), it appears necessary to test every proposed geometry, particularly any which include more than 2 pipes. This observation is based on the strong geometry dependence of this test. The amount of testing required for this approach significantly limits its practicality. Alternatively, requirements for testing can be kept to a more workable level if the objective of this test is limited to identifying which pipe

materials have acceptable resistance to the spread of flame. This objective may be accomplished by establishing an acceptable char height for a reference geometry (e.g., 2.5 m for 2 inch pipes with a 2 inch spacing). If the reference geometry is used to perform the test, the results may be interpreted immediately. If another geometry is used the results can be readily converted using Equation 4.4

F) The IMO test procedure, as modified was executable. Two procedural difficulties remain. These difficulties involve sample widths and the measurement of flame spread. Given that the test procedure allows for the testing of different diameters of pipe (and therefore different numbers of segments), the widths of the samples are not constant. This requires that insulation be applied to the edges of the sample. The exact requirements will vary from sample to sample. The spread of flame across the surface of the sample is measured by eye and stopwatch with the aid of "position indicating wires." This method of measurement is, at best, not very precise. It is made less precise because the flame front does not progress uniformly across the surface of the test material.

G) The repeatability of the data obtained using the IMO test procedure varied markedly. At best, replicate data had standard deviations of less than 5% of the measured value. At worst, standard deviations were over 60% of the measured value. The worst repeatability did not occur for measured values which were small or at the limits of the capability of the instrumentation. Repeatability was best for total heat released and peak heat release rate. Repeatability was worst for heat for sustained burning and critical flux at extinction.

H) Results from the IMO test procedure were expected to depend significantly on pipe diameter, number of segments, and sample size (including wall thickness). The results were anticipated to depend on these criteria because the heat flux and view factors depend on sample curvature (pipe diameter and number of segments), and the total energy content depends on sample mass (size). With the exception of total heat release, the data obtained in this investigation show little dependence on the identified extrinsic characteristics. Total heat release appears to be a function of pipe diameter for those materials where thickness is also a function of pipe diameter. The apparent divergence between predictions and results appears to be due largely to the fact that changes in pipe curvature cause heat flux and view factors to vary in opposing directions. Since there is little curvature based variation in the data, it is reasonable to conclude that the effects of heat flux and view factor are at least approximately offsetting for the conditions investigated. There is no guarantee that these effects would be offsetting for tests run with other materials and/or pipe diameter/number of segments combinations.

I) Due to the demonstrated dependence of the total heat flux and the potential dependence of the other measured parameters on extrinsic properties, comparison of test results obtained using different test geometries is suspect. This situation could be remedied by selecting one, standard geometry. A method for testing with other geometries and "correcting" to the selected one was not discovered for the IMO test method (as it was with the IEC method).

J) Based on the currently proposed acceptance criteria for the IMO test procedure, only three materials of the 9 tested are acceptable.

K) The IMO test procedure is relatively easy to run and uses equipment that is already found in some test labs. The results from this test procedure have poor repeatability, are geometrically sensitive and cannot yet be corrected to account for geometric differences. The IEC test procedure is also relatively easy to run. It requires a larger test apparatus which is not widely available. The results from this test procedure have reasonably good repeatability and can be readily corrected for differences in geometry.

7.0 REFERENCES

1. Fire Endurance Testing Of Fiberglass Piping Report, April 1992, Coast Guard Report No. CG-D-04-93, Available from the National Technical Information Service, Springfield, VA, 22161, Government Accession No. AD-A268638

Appendix A

Tests on Electric Cables Under Fire Conditions

INTERNATIONAL ELECTROTECHNICAL COMMISSION

TESTS ON ELECTRIC CABLES UNDER FIRE CONDITIONS

Part 3: Tests on bunched wires or cables

FOREWORD

- 1) The formal decisions or agreements of the IEC on technical matters, prepared by Technical Committees on which all the National Committees having a special interest therein are represented, express, as nearly as possible, an international consensus of opinion on the subjects dealt with.
- 2) They have the form of recommendations for international use and they are accepted by the National Committees in that sense.
- 3) In order to promote international unification, the IEC expresses the wish that all National Committees should adopt the text of the IEC recommendation for their national rules in so far as national conditions will permit. Any divergence between the IEC recommendation and the corresponding national rules should, as far as possible, be clearly indicated in the latter.

PREFACE

This report has been prepared by IEC Technical Committee No. 20: Electric Cables.

A first draft was discussed at the meeting held in Florence in 1980. A new draft was circulated under the Accelerated Procedure in October 1980, as a result of which a draft, Document 20(Central Office)145, was submitted to the National Committees for approval under the Six Months' Rule in April 1981.

The National Committees of the following countries voted explicitly in favour of publication.

Argentina	Netherlands
Australia	New Zealand
Austria	Poland
Belgium	Romania
Canada	South Africa (Republic of)
China	Spain
Denmark	Sweden
German Democratic Republic	Switzerland
Ireland	Union of Soviet Socialist Republics
Italy	United Kingdom
Japan	United States of America

The French National Committee submitted a negative vote because it considers, firstly, that contrary to the contents of the introduction, the test method is not stabilized and its reliability not established and secondly, that the publication does not draw attention to the conventional views of the method and does not give any indication of its reproducibility and repeatability nor the spread of results that may arise.

TESTS ON ELECTRIC CABLES UNDER FIRE CONDITIONS

Part 3: Tests on bunched wires or cables

1. Introduction

IEC Publication 332-1: Tests on Electric Cables under Fire Conditions, Part 1: Test on a Single Vertical Insulated Wire or Cable, specifies a method of test for the flame propagation characteristics of a single vertical insulated wire or cable, and it cannot be assumed that because a sample of cable complies with the requirements in Part 1 that a bunch of cables will behave in a similar manner.

Consequently this report has been prepared to give a method of test for the flame propagation characteristics of a bunch of cables. Propagation of fire depends on a number of factors but it is in particular a function of the total volume of combustible material in the cable run. Three test categories are included to meet various user requirements.

2. Scope

This report recommends a method of test for the flame propagation characteristics of a bunch of cables.

This report recommends three test categories, these being assessed by the amount of combustible material contained in one metre of the bunched cables being tested.

This method of test is a type test for cables.

3. Test sample and categories

The test sample should comprise a number of pieces of cable each 3.5 m long.

The total number of 3.5 m lengths of cable in the test sample should be in accordance with one of the three categories as follows:

Category A

The number of cable lengths required to give a total volume of combustible material of 7 litres per metre.

Category B

The number of cable lengths required to give a total volume of combustible material of 3.5 litres per metre.

Category C

The number of cable lengths required to give a total volume of combustible material of 1.5 litres per metre.

Note. — When calculating the number of cables lengths in the test sample, the sample should be rounded to the nearest whole number.

4. Details of the test rig

The test rig (Figure 1, page 12) should comprise a vertical test chamber having a width of 1 m, a depth of 2 m and a height of 4 m and the floor of the chamber should be raised 150 mm above the ground level. The test chamber should be nominally airtight along its sides, air being admitted, without any substantial obstruction, at the base of the test chamber through an aperture 800 mm × 400 mm situated 150 mm from the front wall of the test chamber.

Note. — Consideration is being given to the use of a controlled air flow rate, in the range 4.5 m³/min to 10 m³/min, through the test chamber and after agreement has been reached an early amendment on speed and method is envisaged.

An outlet 300 mm × 1 000 mm should be made at the rear edge of the top of the test chamber. The back and sides of the test chamber should be thermally insulated to give a coefficient of heat transfer of approximately 0.7 W/(m²·K). For example a steel plate 1.5 mm thick covered with 65 mm of mineral wool with a suitable external cladding is satisfactory (see Figure 1a, page 13). The cables to be tested should be fixed to a steel ladder (see Figure 2, page 14) mounted within the test chamber such that the distance between the ladder and the rear wall of the chambers is 150 mm.

Smoke cleaning attachment

Legal requirements may make it necessary for equipment for collecting and washing the smoke to be fitted to the test chamber. This equipment should be such as to collect the smoke leaving the chamber but not cause a change in the air flow rate through the test chamber.

5. Method of mounting the test sample

The test sample should be attached to each rung of the steel ladder using steel wire ties. The total width of the mounted cable sample should not exceed 300 mm and the sample should be approximately centred on the ladder.

Cables having an individual conductor cross-section greater than 35 mm² should be fixed to the ladder spaced apart by half the cable diameter but the spacing should not exceed 20 mm.

When the number of cables to be mounted with spacing is such that mounting them all on one side of the ladder will exceed the width of 300 mm then the cables should be mounted using both sides of the ladder, first filling the front and then starting in the centre of the rear of the ladder (see Figure 3, page 15).

All other cables should be fixed to the front of the ladder in multiple layers with the cables touching one another.

6. Ignition source

The ignition source should be a ribbon type propane gas burner whose flame producing surface consists of a flat metal plate 341 mm long and 30 mm wide through which 242 holes 1.32 mm in diameter are drilled on 3.2 mm centres in three staggered rows of 81, 80 and 81 holes each to form an array having the nominal dimensions 257 mm × 4.5 mm as shown in Figure 4, page 16. As the burner plate may be drilled without the use of a drilling jig the spacing of the holes may vary slightly. Additionally a row of small holes may be milled on each side of the burner plate to serve as pilot holes with the function of keeping the flame burning.

The burner should be fitted with an accurate means of controlling the input of fuel and air to the burner. For the purpose of this test the fuel input rate should be $73.7 \pm 1.68 \times 10^6$ J/h ($70\,000 \pm 1600$ Btu/h) and the air input 4.6 ± 0.28 m³/h (163 ± 10 ft³/h).

Note. — To ensure reproducibility between results from different testing stations, it is recommended that a standard burner, which is readily available, be used. For details see Appendix A.

7. Positioning of the ignition source

The burner should be arranged horizontally at a distance 75 mm from the front surface of the cable sample and 600 mm above the floor of the test chamber. The point of application of the burner flame should lie in the centre between two cross-bars on the ladder and at least 500 mm above the lower end of the sample (see Figure 3, page 15).

8. Test procedure

8.1 Test condition

The test should not be carried out if the external wind speed measured by an anemometer fitted on the top of the test rig is greater than 5 m/s, and should not be carried out if the temperature of the walls of the chamber is below 5 °C or above 40 °C.

8.2 Conditioning of the test rig and sample

The cables mounted on the ladder should be conditioned at a temperature of 23 ± 5 °C for 3 h at least before commencing the test. The test chamber should be dry.

8.3 Time of application of the flame

In the case of cables samples in Category A and Category B the test flame should be applied for 40 min.

Cable samples in Category C should have the test flame applied for 20 min.

9. Performance requirement

Cables tested should comply with the following requirements:

After burning has ceased, the cables should be wiped clean and the charred or affected portion should not have reached a height exceeding 2.5 m above the bottom edge of the burner, measured at the front and rear of the cable assembly.

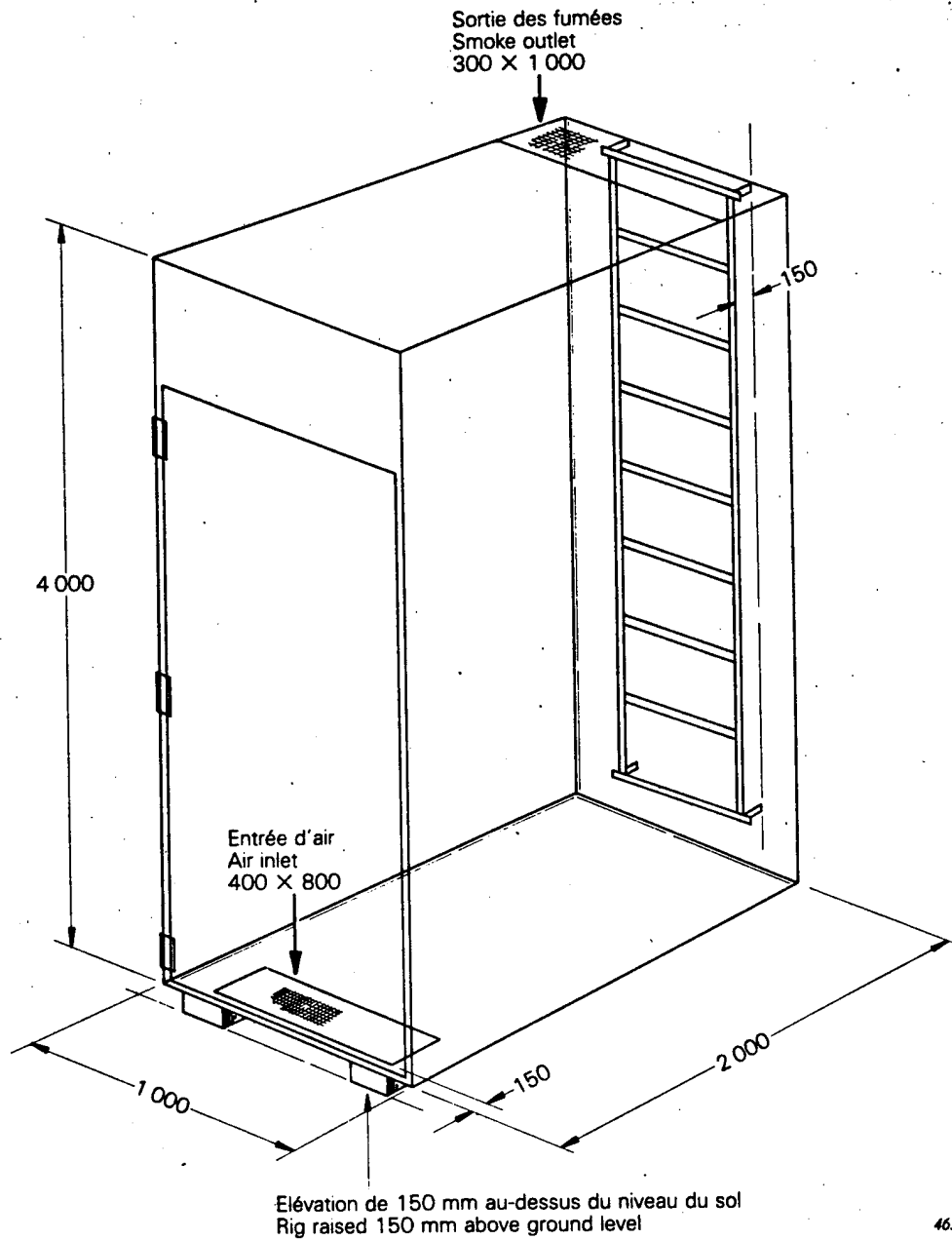
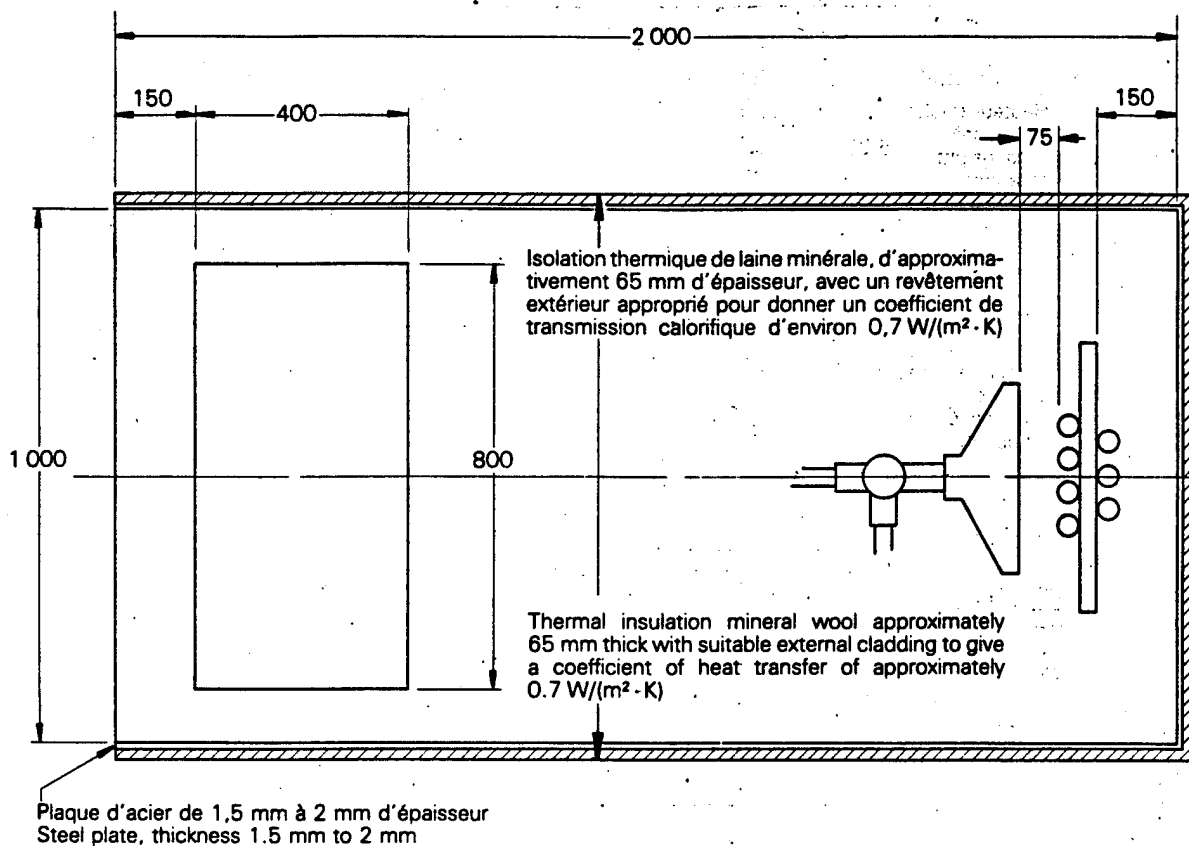
*Dimensions en millimètres**Dimensions in millimetres*

FIG. 1. — Equipement d'essai au feu.
Fire test rig.

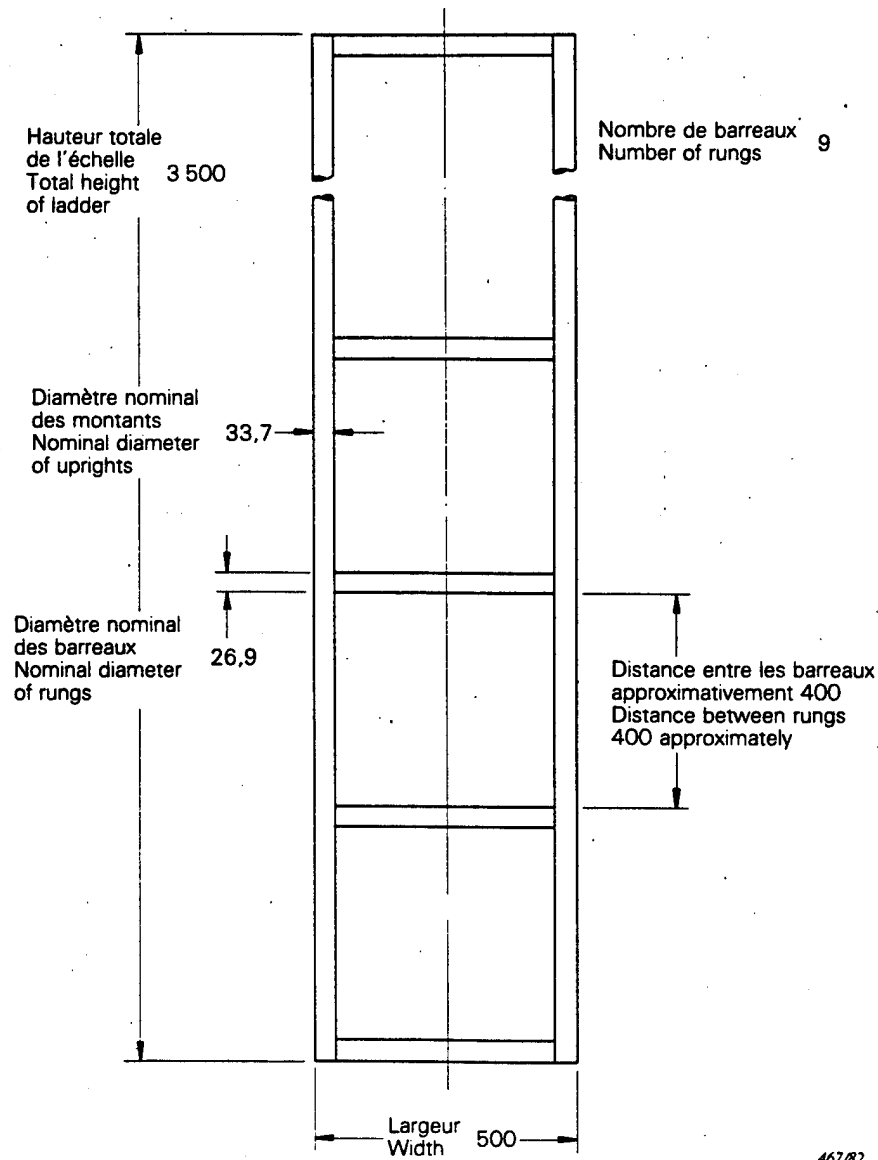
Dimensions en millimètres

Dimensions in millimetres



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FIG. 1a. — Isolation thermique de l'arrière et des côtés de la chambre d'essai.
Thermal insulation of back and sides of the test chamber.

*Dimensions en millimètres**Dimensions in millimetres*

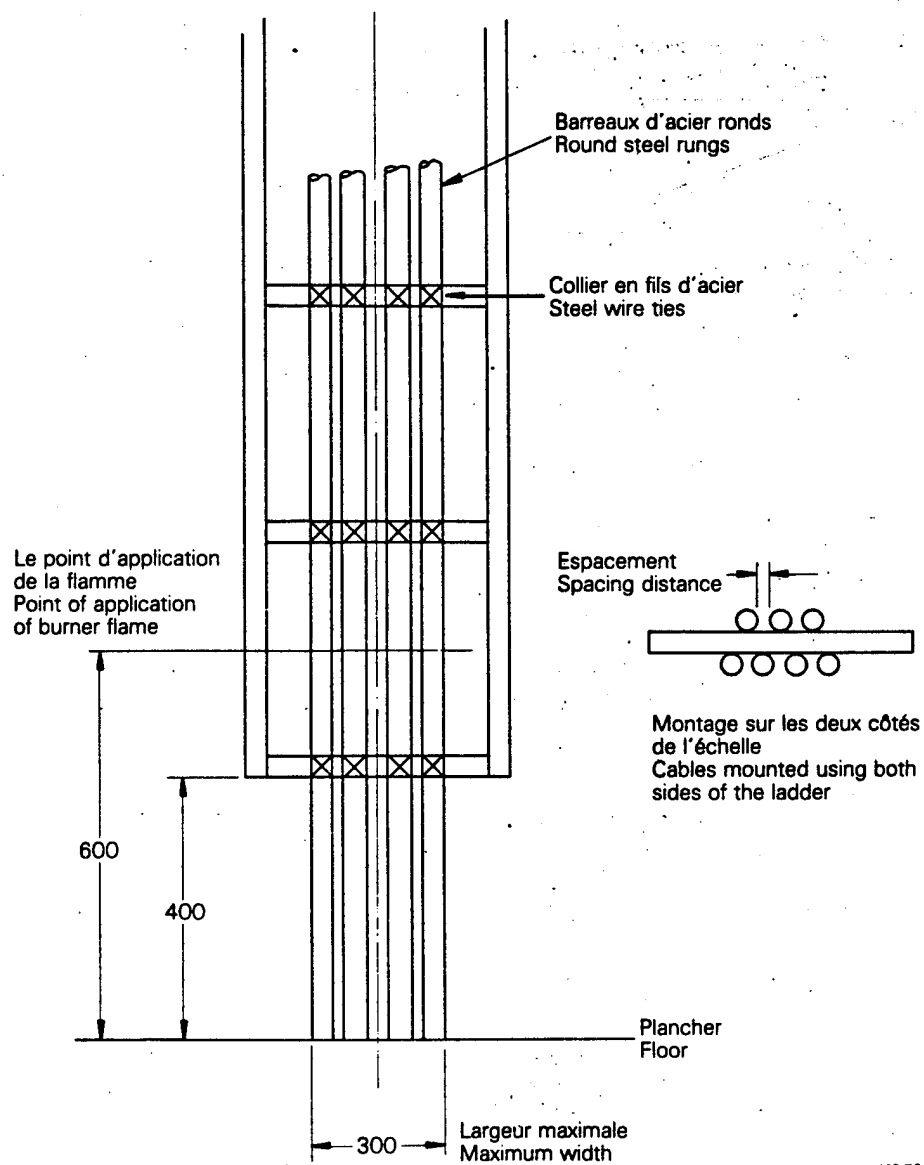
467/82

Note. — Les dimensions des tubes doivent être conformes à la Norme ISO 65.
 Tube dimensions shall be in accordance with ISO Standard 65.

FIG. 2. — Echelle de câbles pour l'essai.
Cable test ladder.

Dimensions en millimètres

Dimensions in millimetres

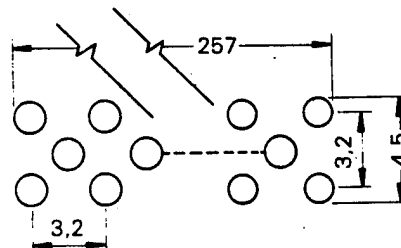
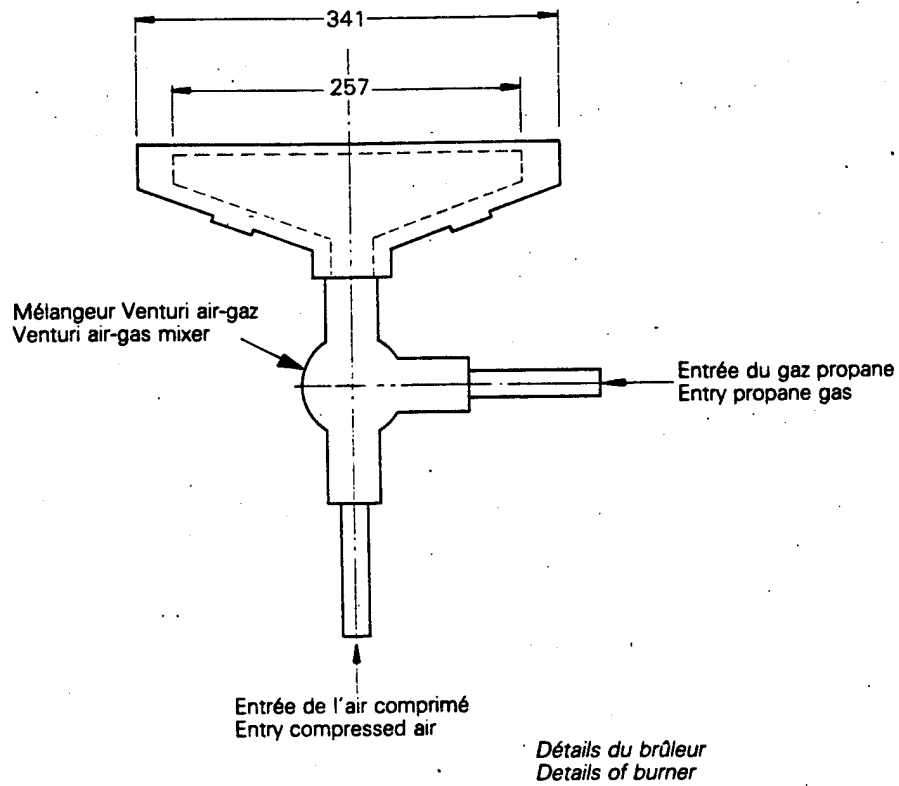


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FIG. 3. — Disposition des échantillons sur l'échelle.
Arrangement of test samples on ladder.

Dimensions en millimètres

Dimensions in millimetres



242 trous ronds de 1,32 mm de diamètre placés en quinconce à 3,2 mm de distance sur trois rangées de 81, 80 et 81 trous sur l'avant du brûleur.
242 round holes 1.32 mm in diameter on 3.2 mm centres, staggered in three rows of 81 and 80 and 81, and centred on face of the burner

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Les valeurs sont approchées

Values are approximate

FIG. 4. — Brûleurs.
Burner.

ANNEXE A

DÉTAILS DU BRÛLEUR NORMALISÉ

Un brûleur (numéro de catalogue IOL 11-55) et un mélangeur Venturi (numéro de catalogue 14-18) satisfaisant aux prescriptions de l'article 6 peuvent être fournis par:

APPENDIX A

DETAILS OF STANDARD BURNER

A burner (catalogue number IOL 11-55) and Venturi mixer (catalogue number 14-18) complying with the requirements of Clause 6 can be obtained from:

The American Gas Furnace Company
Spring Street
ELIZABETH
New Jersey 0721
Etats-Unis d'Amérique/United States of America

Appendix B

Test Method and Test Procedure for Flame Spread of Plastic Pipes

TEST METHOD AND TEST PROCEDURE FOR FLAME SPREAD OF PLASTIC PIPES.

1. Test Method.

Flame spread of plastic pipes is to be tested according to IEC Publication 332-3 "Tests on electric cables under fire conditions" with the following modification.

2. Test Conditions.

Two empty pipe samples shall be mounted vertically in the rig with a distance of 5 ± 1 cm between the pipes (see Figure 3). The lower ends of the pipes shall be closed. If joints are included in the samples, they should be checked for tightness.

The samples shall as far as possible be mounted according to the manufacturer's instructions.

The test flame shall be applied for 20 minutes.

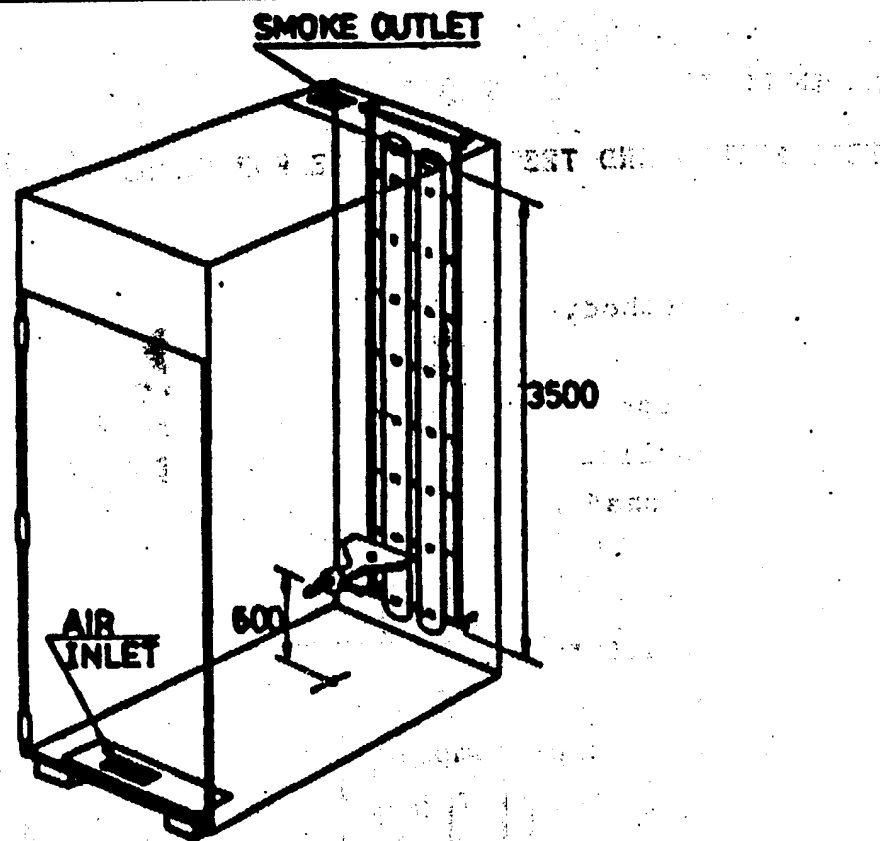
At least 2 tests shall be carried out on each size to be tested.

3. Acceptance Criteria.

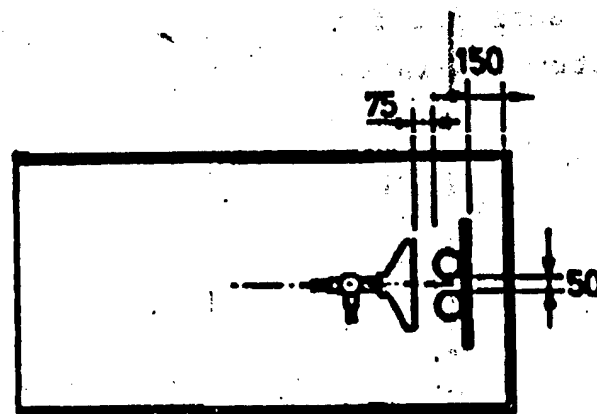
After burning has ceased the pipes shall be wiped clean. The charred or affected portion shall not have reached a height exceeding 2.5 m above the bottom edge of the burner, measured at the front and rear of the pipes.

4. Alternative Test Methods and Test Procedures.

Other test methods and test procedures considered to be at least equivalent may be accepted.



a) TEST CHAMBER WITH SAMPLES MOUNTED



b) TEST CHAMBER SEEN FROM ABOVE

FIG. 3 FLAME SPREAD TEST
(IEC Publication 332-3)

Appendix C

IMO Resolution A.653(16)



ASSEMBLY - 16th session
Agenda item 10

IMO

RESOLUTION A.653(16)

adopted on 19 October 1989

RECOMMENDATION ON IMPROVED FIRE TEST PROCEDURES FOR
SURFACE FLAMMABILITY OF BULKHEAD, CEILING AND
DECK FINISH MATERIALS

THE ASSEMBLY,

RECALLING Article 15(j) of the Convention on the International Maritime Organization concerning the functions of the Assembly in relation to regulations and guidelines concerning maritime safety,

RECALLING FURTHER that it adopted, by resolution A.564(14), the Revised Recommendation on Fire Test Procedures for Surface Flammability of Bulkhead, Ceiling and Deck Finish Materials, with reference to the term "low flame spread" in regulations II-2/3.8, II-2/34.3 and II-2/49.1 of the International Convention for the Safety of Life at Sea, 1974, as amended,

RECOGNIZING the need to improve these test procedures in the light of experience gained,

HAVING CONSIDERED the recommendation made by the Maritime Safety Committee at its fifty-seventh session,

1. ADOPTS the Recommendation on Improved Fire Test Procedures for Surface Flammability of Bulkhead, Ceiling and Deck Finish Materials, the text of which is annexed to the present resolution and which supersedes the Revised Recommendation annexed to resolution A.564(14);

W/2724e

2. RECOMMENDS Governments concerned to apply the Recommendation on Improved Fire Test Procedures set out in the Annex, in lieu of the Revised Recommendation as annexed to resolution A.564(14) in conjunction with the guidelines on the evaluation of fire hazard properties of materials set out in resolution A.166(ES.IV).

ANNEX

RECOMMENDATION ON IMPROVED FIRE TEST PROCEDURES FOR SURFACE FLAMMABILITY
OF BULKHEAD, CEILING AND DECK FINISH MATERIALS

1 SCOPE

This Recommendation specifies a procedure for measuring fire characteristics of bulkhead, ceiling and deck finish materials as a basis for characterizing their flammability and thus their suitability for use in marine construction.

2 WARNING

2.1 Ignition hazards

The use of this test method involves the generation of very high heat flux levels which are capable of causing ignition of some materials such as clothing following even brief exposures. Precautions should be taken to avoid accidental ignitions of this type.

2.2 Toxic fume hazards

The attention of the user of this test is drawn to the fact that the fumes from burning materials often include carbon monoxide. Other more toxic products may in many instances be produced. Suitable precautions should be taken to avoid any extended exposure to these fumes.

3 DEFINITIONS

Certain terms used in this Recommendation require definition for clarity. Other fire characteristic terms are also used; these are defined hereunder but relate only to the results of measurements by this specific test method.

3.1 Compensating thermocouple

A thermocouple for the purpose of generating an electrical signal representing long-term changes in stack metal temperatures. A fraction of the signal generated is subtracted from the signal developed by the stack gas thermocouples.

3.2 Critical flux at extinguishment

A flux level at the specimen surface corresponding to the distance of farthest advance and subsequent self-extinguishment of the flame on the centreline of a burning specimen. The flux reported is based on calibration tests with a dummy specimen.

3.3 Dummy specimen

A specimen used for standardizing the operating condition of the equipment; it should be roughly 20 mm thickness, $800 \pm 100 \text{ kg/m}^3$ density and should meet the requirements of resolution A.472(XII) as non-combustible.

3.4 Special calibration dummy specimen

A dummy specimen as defined by figure 14 intended only for use in calibration of heat flux gradient along with specimen.

3.5 Fume stack

A box-like duct with thermocouples and baffles through which flames and hot fumes from a burning specimen pass. Its purpose is to permit measurement of the heat release from the burning specimen.

3.6 Heat for ignition

The product of the time from initial specimen exposure until the flame front reaches the 150 mm position and the flux level at this position; this latter obtained in prior calibration of the apparatus.

3.7 Heat release of specimen

The observed heat release under the variable flux field imposed on the specimen and measured as defined by the test method.

3.8 Heat for sustained burning

The product of time from initial specimen exposure until arrival of the flame front and the incident flux level at that same location as measured with a dummy specimen during calibration. The longest time used in this calculation should correspond to flame arrival at a station at least 30 mm prior to the position of furthest flame propagation on the centreline of the specimen.

3.9 Reverberatory wires

A wire mesh located in front of, but close to, the radiating surface of the panel heat source. This serves to enhance the combustion efficiency and increase the radiance of the panel.

3.10 Viewing rakes

A set of bars with wires spaced at 50 mm intervals for the purpose of increasing the precision of timing flame front progress along the specimen.

4 PRINCIPLE OF THE TEST

This test provides methods for evaluating flammability characteristics of 155 mm x 800 mm specimens in vertical orientation. The specimens are exposed to a graded radiant flux field supplied by a gas-fired radiant panel. Means are provided for observing the times to ignition, spread and extinguishment of flame along the length of the specimen as well as for measuring the compensated millivolt signal of the stack gas thermocouples as the burning progresses. Experimental results are reported in terms of: heat for ignition, heat for sustained burning, critical flux at extinguishment and heat release of specimen during burning.

5 FACILITY AND APPARATUS REQUIREMENTS

5.1 General

A detailed description of the facility and apparatus required for conduct of this test is included in the appendix. Compliance with the appendix forms an essential requirement of the test method. The equipment needed may be summarized as follows:

5.1.1 Special test room fitted with fume exhaust system as well as fresh air inlet.

5.1.2 Radiant panel frame fitted with blower or other source of combustion air, a methane* or natural gas supply system with suitable safety controls, and a radiant panel heat source, with reverberatory wires, arranged to radiate on a vertical specimen. Alternatively, an electrically heated radiant source of the same dimensions may be used provided it can expose the specimen to the heat flux distribution shown in table 1. The effective source temperature of any radiant panel is not greater than 1,000°C.

5.1.3 The specimen holder frame, three specimen holders, two parts of pilot burners, specimen holder guides, viewing rakes and a viewing mirror.

5.1.4 A specimen fume stack with both stack gas and stack temperature compensating thermocouples together with a means for adjusting the magnitude of the compensation signal.

5.1.5 Instrumentation comprising a chronograph, digital or sweep second electric clock, a digital millivoltmeter, a two-channel millivolt recorder, gas-flowmeter, heat-fluxmeters, a wide angle total radiation pyrometer and a stopwatch. Use of a data acquisition system to record both panel radiance and the heat release stack signal during test will facilitate data reduction.

* The use of gases other than methane or natural gas is not recommended although with changes in panel-specimen spacing it has been reported possible to use the equipment with propane up to flux levels of 50 kw/m².

6 CALIBRATION

Mechanical, electrical and thermal calibrations should be performed as described in the appendix. These adjustments and calibrations should be performed following initial installation of the apparatus and at other times as the need arises.

6.1 Monthly verification

The calibration of the flux distribution on the specimen and the proper operation of the fume stack with its thermocouple system should be confirmed by monthly tests, or at more frequent intervals if this is found necessary (see 4.3.1 and 4.6 in the appendix).

6.2 Daily verification

As a means of assuring continued proper adjustment of the apparatus, the following tests should be performed on a daily basis, or more frequently if the nature of the specimens makes this necessary.

6.2.1 Adjustment of the pilot burner, the acetylene and air supply should be adjusted to provide a flame length of about 230 mm*. When this has been done, the flame length as viewed in a darkened laboratory will be seen to extend about 40 mm above the upper retaining flange of the specimen holder. The burner spacing from the specimen is adjusted while the radiant source is operating by the use of softwood splines of 3 mm thickness and of 10 mm and 12 mm width. When these splines are moved during a two second exposure along the flame length, between the pilot burner flame and a dummy specimen surface, the 10 mm spline should not be charred but the 12 mm spline should show char. With the specimen in the vertical position, the charring of the 12 mm spline should occur over a vertical distance of at least 40 mm from the upper exposed edge of the specimen (see figure 9 in the appendix).

* It is recommended that, to give increased precision, acetylene rather than other gases be used wherever possible.

6.2.2 The stack gas thermocouples should be cleaned by light brushing at least daily. This cleaning may be required even more frequently, in some instances before each test, when materials producing heavy soot clouds are tested. These thermocouples should also be individually checked for electrical continuity to ensure the existence of a useful thermojunction. Following daily cleaning of the parallel connected stack gas thermocouples, both they and the compensating junction should be checked to verify that the resistance between them and the stack is in excess of 10^6 ohms.

6.3 Continuous monitoring of operation

A dummy specimen should remain mounted in the position normally occupied by a specimen whenever the equipment is in stand-by operation. This is a necessary condition of the continuous monitoring procedure which is accomplished by measuring:

- .1 the millivolt signals from both the stack thermocouples and the total radiation pyrometer mounted securely on the specimen holder frame facing the surface of the radiant panel; or
- .2 the millivolt signals from both the stack thermocouples and a heat-fluxmeter positioned at 350 mm from the exposed hot end of a marine board specimen of about 20 mm thickness (see appendix, paragraph 4.3.2).

Either of these measurement methods would be satisfactory for determining that an appropriate thermal operating level has been achieved. The use of the radiation pyrometer is preferable since it permits continuous monitoring of panel operating level even when tests are in progress. Both signals should remain essentially constant for three minutes prior to the test. The observed operating level of either the radiation pyrometer or the fluxmeter should correspond, within 2%, to the similar required level specified in table 1 and referred to in the calibration procedure mentioned in 6.1 above.

7 SPECIMENS

7.1 Number required

Three specimens should be tested for each different exposed surface of the product evaluated and applied.

7.2 Dimensions

The specimens should be $155 \pm \frac{0}{5}$ mm wide by $800 \pm \frac{0}{5}$ mm long, and should be representative of the product.

7.2.1 Specimen thickness: materials and composites of normal thickness 50 mm or less should be tested using their full thickness, attaching them, by means of an adhesive if appropriate, to the substrate to which they will be attached in practice. For materials and composites of normal thickness greater than 50 mm, the required specimens should be obtained by cutting away the unexposed face to reduce the thickness to $50 \pm \frac{3}{0}$ mm.

7.3 Composites

Assembly should be as specified in 7.2. However, where thin materials or composites are used in the fabrication of an assembly, the presence of an air gap and/or the nature of any underlying construction may significantly affect the flammability characteristics of the exposed surface. The influence of the underlying layers should be recognized and care taken to ensure that the test result obtained on any assembly is relevant to its use in practice.

7.4 Metallic facings

If a bright metallic faced specimen is to be tested, it should be painted with a thin coat of flat black paint prior to conditioning for test.

7.5 Marking specimens

A line should be marked centrally down the length of the tested face of each specimen. Caution should be exercised to avoid the use of a line which would influence specimen performance.

7.6 Conditioning of specimens

Before test, the specimens should be conditioned to constant moisture content, at a temperature of $23 \pm 2^\circ\text{C}$, and a relative humidity of $50 \pm 10\%$. Constant moisture content is considered to be reached when, following two successive weighing operations, carried out at an interval of 24 hours, the measured masses do not differ by more than 0.1% of the mass of the specimen.

8 TEST PROCEDURE

8.1 General considerations

The test method involves mounting the conditioned specimen in a well-defined flux field and measuring the time of ignition, spread of flame, its final extinguishment together with a stack thermocouple signal as an indication of heat release by the specimen during burning.

8.1.1 Prepare a properly conditioned specimen for test in a cool holder away from the heat of the radiant panel. Prior to insertion in the specimen holder, the back and edges of the specimen should be wrapped in a single sheet of aluminium foil of 0.02 mm thickness and dimensions of $(175 + a) \text{ mm} \times (820 + a) \text{ mm}$ where "a" is twice the specimen thickness. When inserted in the specimen holder each specimen should be backed by a cool $10 \pm 2 \text{ mm}$ board of non-combustible refractory insulating material with the same lateral dimensions and density as the dummy specimen. When mounting non-rigid specimens in the holder, shims should be placed between specimen and holder flange to ensure that the exposed specimen face remains at the same distance from the pilot flame as a rigid specimen. For such materials, the shims may often only be required for a 100 mm length at the hot end of the specimen.

8.1.2 The dummy specimen in a specimen holder should be mounted in position facing the radiant panel. The equipment fume exhaust system should be started.

8.1.3 The radiant panel is operated to realize the test conditions as specified in 6.3. Start the millivolt recorder recording the output signal of the stack thermocouples, as well as signal from the total radiation pyrometer or heat-fluxmeter positioned, as described in 6.3.2.

8.1.4 When the radiant panel and stack signals have attained equilibrium, after the preheat period, light the pilot flame, adjust its fuel flow rate and observe both signals for at least three minutes and verify continued signal stability.

8.1.5 After both signals reach stable levels, remove the dummy specimen holder and insert the specimen in the test position within 10 s. Immediately start both the clock and chronograph.

8.1.6 Operate the event marker of the chronograph to indicate the time of ignition and arrival of the flame front during the initial rapid involvement of the specimen. The arrival at a given position should be observed as the time at which the flame front at the longitudinal centreline of the specimen is observed to coincide with the position of two corresponding wires of the viewing rakes. These times are recorded manually both from measurement on the chronograph chart and from observations of the clock. As far as possible, the arrival of the flame front at each 50 mm position along the specimen should be recorded. Record both the time and the position on the specimen at which the progress of flaming combustion ceases. The panel operating level, as well as stack signals, should be recorded throughout the test and continued until test termination.

8.1.7 Throughout the conduct of the test, no change should be made in the fuel supply rate to the radiant panel to compensate for variations in its operating level.

8.2 Duration of test

The test should be terminated, the specimen removed, and the dummy specimen in its holder reinserted when any one of the following is applicable:

- .1 the specimen fails to ignite after a 10 min exposure;
- .2 3 min have passed since all flaming from the specimen ceased;
- .3 flaming reaches the end of the specimen or self-extinguishes and thus ceases progress along the specimen. This criterion should only be used when heat release measurements are not being made.

8.2.1 Operations 8.1.1 to 8.1.7 should be repeated for two additional specimens (see 8.3).

8.3 Conditions of retest

In the event of failure, during test of one or more specimens, to secure complete flame spread times or a reasonable heat release curve, the data secured should be rejected and a new test or tests performed. Such failures might involve, but not be limited to, incomplete observational data or malfunction of data logging equipment. Excessive stack signal baseline drift should also require further equipment stabilization and retest.

8.3.1 In the event that the first two or three specimens do not ignite following exposure for 10 min, at least one specimen should be tested with the pilot flame angled to impinge on the upper half of the specimen. If this specimen ignites, two additional tests should be run under the same conditions.

8.3.2 If a specimen shows extensive loss of incompletely burned material during test, at least one additional specimen, restrained in the testing frame by poultry netting, should be tested and the data secured reported separately.

8.4 Observations

In addition to the recording of the experimental data, observations should be made and recorded on general behaviour of the specimen including: glowing, charring, melting, flaming drips, disintegration of the specimen, etc.

9 DERIVED FIRE CHARACTERISTICS

Experimental results should be reported in terms of the thermal measurements of incident flux measured with a dummy specimen in place.

The results should not be adjusted to compensate for changes in the thermal output of the radiant panel during the conduct of the test. The following data should be derived from the test results.

9.1 Heat for ignition

As defined in 3.6.

9.2 Heat for sustained burning

A list of the values of this characteristic as defined in paragraph 3.8.

9.3 Average heat for sustained burning

An average of the values for the characteristic defined in 3.8 measured at different stations, the first at 150 mm and then at subsequent stations at 50 mm intervals, through the final station or the 400 mm station, whichever value is the lower.

9.4 Critical flux at extinguishment

A list of the values of this characteristic for the specimens tested and the average of these values.

9.5 Heat release of the specimen

Both a heat release time curve and a listing of the peak and total integrated heat release should be secured from the experimental data. They should be corrected for the non-linearity of the heat release calibration curve.

The curve of the millivolt signal from the stack thermocouples should include at least 30 s of the initial 3 min steady state verification period as well as the starting transient just prior to and following specimen insertion. In converting millivolt signals to heat release rate, the zero release level of the calibration curve should be set at the level of the initial steady state just prior to test of the specimen involved. See figure 13.

9.5.1 Total heat release

The total heat release is given by integration of the positive part of the heat release rate during the test period (see figure 13).

9.5.2 Peak heat release rate

The peak heat release rate is the maximum of the heat release rate during the test period (see figure 13).

10 CLASSIFICATION

Materials giving average values for all of the surface flammability criteria not exceeding those listed in the following table, are considered to meet the requirement for low flame spread in compliance with regulations II-2/3.8, II-2/34 and II-2/49 of the International Convention for the Safety of Life at Sea, 1974, as amended.

SURFACE FLAMMABILITY CRITERIA

Bulkhead, wall and ceiling linings				Floor coverings			
CFE kW/m ²	Q _{sb} MJ/m ²	Q _t MJ	Q _p kW	CFE kW/m ²	Q _{sb} MJ/m ²	Q _t MJ	Q _p kW
≥20.0	≥1.5	≤0.7	≤4.0	≥7.0	≥0.25	≤1.5	≤10.0

Where CFE = Critical flux at extinguishment

Q_{sb} = Heat for sustained burning

Q_t = Total heat release

Q_p = Peak heat release rate

11 TEST REPORT

The test report should include both the original data, observations made on each specimen tested and the derived fire characteristics. The following information should be supplied:

- .1 Name and address of testing laboratory.
- .2 Name and address of sponsor.
- .3 Name and address of manufacturer/supplier.
- .4 Full description of the product tested including trade name, together with its construction, orientation, thickness, density and, where appropriate, the face subjected to test. In the case of specimens which have been painted or varnished, the information recorded should include the quantity and number of coats applied, as well as the nature of the supporting materials.
- .5 Data from the test including:
 - .5.1 number of specimens tested;
 - .5.2 type of pilot flame used;
 - .5.3 duration of each test;
 - .5.4 observations recorded in accordance with 8 above;
 - .5.5 other relevant observations from the test, such as flashing, unstable flame front, whether or not pieces of burning materials fall off, separations, fissures, sparks, fusion, changes in form;
 - .5.6 derived fire characteristics as described in 9 above;
 - .5.7 classification of the material.

.6 A limiting use statement.

Note: The test results relate only to the behaviour of the test specimens of a product under the particular conditions of the test; they are not intended to be the sole criterion for assessing the potential fire hazard of the product in use.

APPENDIX

This appendix provides technical information intended to permit construction, erection, alignment and calibration of the physical equipment required for the conduct of tests by this procedure.

1 TEST EQUIPMENT FABRICATION

Figures 1 to 5 show photographs of the equipment as assembled ready for test. Detailed drawings and a parts list are available from the IMO Secretariat. These provide engineering information necessary for the fabrication of the main frame, specimen holders, stack and other necessary parts of the equipment.

1.1 Brief parts list for the test equipment assembly includes:

- .1 The main frame (figure 1) which comprises two separate sections, the burner frame and the specimen support frame. These two units are bolted together with threaded rods permitting flexibility in mechanical alignment.
- .2 Specimen holders which provide for support of the specimens during test. At least two of these are required. Three prevent delays resulting from required cooling of holders prior to mounting specimens.
- .3 A specimen fume stack fabricated of stainless steel sheet of 0.5 ± 0.05 mm thickness complete with gas and stack metal compensating thermocouples.
- .4 The radiant panel which has radiating surface dimensions of 280 mm x 483 mm. It has been specially fabricated for use with this equipment through use of commercially available porous refractory tiles.

- .5 The blower for combustion air supply, radiant panel, air flow metering device, gas control valves, pressure reducer and safety controls which are all mounted on the burner frame (figure 3). Requirements are summarized below:
- .5.1 Air supply of about $30 \text{ m}^3/\text{h}$ at a pressure sufficient to overcome the friction losses through the line, metering device and radiant panel. The radiant panel drop amounts to only a few millimetres of water.
- .5.2 The gas used may be either natural gas or methane. The use of gas other than methane or natural gas is not recommended*, although with changes in panel-specimen spacing, it is possible to use the equipment with propane at flux levels of 50 kW/m^2 . A pressure regulator should be provided to maintain a constant supply pressure. Gas is controlled by a manually adjusted needle valve. No venturi mixer is necessary. Safety devices include an electrically operated shutoff valve to prevent gas flow in the event of electric power failure, air pressure failure and loss of heat at the burner surface. The gas flow requirements are roughly $1.0 \text{ m}^3/\text{h}$ to $3.7 \text{ m}^3/\text{h}$ for natural gas or methane at a pressure to overcome line pressure losses.
- .6 The specimen holder, pilot flame holder, fume stack, flame front viewing rakes, radiation pyrometer and mirror are all assembled on the specimen support frame. The arrangement of parts on this frame is shown in figures 1 and 2.
- .7 A dummy specimen approximately 20 mm thick, made of non-combustible refractory board of $800 \pm 100 \text{ kg/m}^3$ density should be continuously mounted on the apparatus in the position of the specimen during operation of the equipment. This dummy specimen should only be removed when a test specimen is to be inserted.

* Flashback limits the maximum operating level with propane.

2 INSTRUMENTATION

2.1 Total radiation pyrometer

This should have a sensitivity substantially constant between the thermal wave lengths of $1\text{ }\mu\text{m}$ and $9\text{ }\mu\text{m}$ and should view a centrally-located area on the panel of about $150\text{ mm} \times 300\text{ mm}$. The instrument should be mounted on the specimen support frame in such a manner that it can view the panel surface.

2.2 Heat fluxmeters

It is desirable to have at least two fluxmeters for this test method. They should be of the thermopile type with a nominal range of 0 kW/m^2 to 50 kW/m^2 and capable of safe operation at three times this rating. One of these should be retained as a laboratory reference standard. They should have been calibrated to an accuracy of within $\pm 5\%$. The target sensing the applied flux should occupy an area not more than 80 mm^2 and be located flush with and at the centre of the water-cooled 25 mm circular exposed metallic end of the fluxmeter. If fluxmeters of smaller diameter are to be used, these should be inserted into a copper sleeve of 25 mm outside diameter in such a way that good thermal contact is maintained between the sleeve and water-cooled fluxmeter body. The end of the sleeve and the exposed surface of the fluxmeter should lie in the same plane. Radiation should not pass through any window before reaching the target.

2.3 Timing devices

Both a chronograph and either an electric clock with a sweep second hand or a digital clock should be provided to measure time of ignition and flame advance. The chronograph for timing ignition and initial flame advance may comprise a strip chart recorder with paper speed of at least 5 mm/s and an event marker pen. Both the chronograph paper drive and the electric clock should be operated through a common switch to initiate simultaneous operation when the specimen is exposed. This may be either hand operated or actuated automatically as a result of complete specimen insertion.

2.4 Recording millivoltmeter

A two-channel strip chart recording millivoltmeter having at least one megohm input resistance should be used to record signals from the fume stack thermocouples and the output from the radiation pyrometer. The signal from the fume stack will in most instances be less than 15 mV but in some cases this may be exceeded by a small amount. The sensitivity of the other channel should be selected to require less than full scale deflection with the total radiation pyrometer or fluxmeter chosen. The effective operating temperature of the radiant panel should not normally exceed 935°C.

2.5 Digital voltmeter

A small digital millivoltmeter will be found convenient for monitoring changes in operating conditions of the radiant panel. It should be capable of indicating signal changes of 10 μ V or less.

3 SPACE FOR CONDUCTING TESTS

3.1 Special room

A special room should be provided for performance of this test. The dimensions of it are not critical but it may be roughly 45 m³ volume with a ceiling height of not less than 2.5 m.

3.2 Fume exhaust system

An exhaust system should be installed above the ceiling with a capacity for moving air and combustion products at a rate of 30 m³/min. The ceiling grill opening to this exhaust system should be surrounded by a 1.3 m x 1.3 m refractory fibre fabric skirt hanging from the ceiling down to 1.7 \pm 0.1 m from the floor of the room. The specimen support frame and radiant panel should be located beneath this hood in such a way that all combustion fumes are withdrawn from the room.

3.3 The apparatus

This should be located with a clearance of at least one metre separation between it and the walls of the test room. No combustible finish material of ceiling, floor or walls should be located within 2 m of the radiant heat source.

3.4 Air supply

Access to an exterior supply of air, to replace that removed by the exhaust system, is required. This should be arranged in such a way that the ambient temperature remains reasonably stable (for example: the air might be taken from an adjoining heated building).

3.5 Room draughts

Measurements should be made of air speeds near a dummy specimen while the fume exhaust system is operating but the radiant panel and its air supply are turned off. At a distance of 100 mm the air flow perpendicular to the lower edge at midlength of the specimen should not exceed 0.2 m/s in any direction.

4 ASSEMBLY AND ADJUSTMENT

4.1 General

The test conditions are essentially defined in terms of the measured heat flux incident on a dummy specimen during calibration. Radiation transfer will predominate, but convection transfer will also play a part. The flux level incident at the specimen surface is a result of the geometrical configuration between the radiant panel and the specimen, as well as the thermal output from the radiant panel.

4.1.1 Both in original adjustment of test operating conditions and periodic verification of this adjustment, the measured heat flux at the surface of the specimen is the controlling criterion. This heat flux is measured by a fluxmeter (see 2.2) mounted in a special dummy specimen (figure 14).

4.1.2 Between consecutive tests, the operating level should be monitored either by use of a fluxmeter mounted in a dummy specimen as defined in paragraph 3.3 of the Recommendation under "Definitions" or preferably by use of a radiation pyrometer which has been previously periodically calibrated on the basis of the readings of such a fluxmeter. This radiation pyrometer should be rigidly fixed to the specimen-holder frame in such a manner that it continuously views the radiating panel surface (see 2.1).

4.2 Mechanical alignment

Most of the adjustments of the components of the test apparatus may be conducted in the cold condition. The position of the refractory surface of the radiant panel with respect to the specimen must correspond with the dimensions shown in figure 6. These relationships can be achieved by appropriate use of shims between the panel and its mounting bracket, adjustment or separation between the two main frames, and adjustment of the position of the specimen holder guides. Detailed procedures for making these adjustments are suggested in paragraph 5.

4.2.1 The fume stack for heat release measurements should be mechanically mounted on the specimen support frame in the position shown in figure 7. The method of mounting should ensure the relative positions shown but should allow easy stack removal for cleaning and/or repair. The compensating thermocouple should be mounted in such a manner that good thermal contact is achieved while ensuring greater than one megohm electrical resistance from the stack metal wall.

4.3 Thermal adjustment of panel operating level

Thermal adjustment of the panel operating level is achieved by first setting an air flow of about $30 \text{ m}^3/\text{h}$ through the panel. Gas is then supplied and the panel ignited and allowed to come to thermal equilibrium with a dummy specimen mounted before it. At proper operating condition, there should be no visible flaming from the panel surface except when viewed from one side parallel to the surface plane. From this direction, a thin blue flame very close to the panel surface will be observed. An oblique view of the panel after a 15 min warm-up period should show a bright orange radiating surface.

4.3.1 With a water-cooled* fluxmeter mounted in a special dummy specimen, the flux incident on the specimen should correspond to the values shown in table 1. Compliance with this requirement is achieved by adjustment of the gas flow. If necessary, small changes in air flow can be made to achieve the condition of no significant flaming from the panel surface. Precise duplication of the flux measurements specified in table 1 for the 50 mm and 350 mm positions on the basis of the fluxmeter calibration used will fix the flux at the other stations well within the limits called for. This does not mean that all other flux levels are correct, but it does ensure that a fixed configuration or view geometry between the panel and specimen has been achieved. To meet these requirements, it may be necessary to make small changes in the specimen longitudinal position shown in figure 6. A plot and smooth curve should be developed on the basis of the eight flux measurements required. The shape of the curve should be similar to that defined by the typical data shown in table 1. These measurements are important, since the experimental results are reported on the basis of these flux measurements. If a total radiation pyrometer is to be used to monitor panel operation, records of its signal should be kept following successful completion of this calibration procedure. If a change in panel-specimen axial position is necessary to meet the requirements for flux at the 50 mm and 350 mm positions, this should be accomplished by adjusting the screws connecting the two frames. In this way, the pilot position with respect to the specimen will remain unchanged. The specimen stop screw adjustment may be changed to meet the flux requirements in the standard and then the position of the pilot burner mount may require adjustment to maintain the 10 ± 2 mm pilot spacing.

* Water cooling of the fluxmeter is required to avoid erroneous signals at low flux levels. The temperature of the cooling water should be controlled in such a manner that the fluxmeter body temperature remains within a few degrees of room temperature. If this is not done, correction of the flux measurement should be made for temperature difference between the fluxmeter body and room temperature. Failure to supply water-cooling may result in thermal damage to the thermal sensing surface and loss of calibration of the fluxmeter. In some cases repairs and recalibration are possible.

4.3.2 Once these operating conditions have been achieved, all future panel operation should take place with the established air flow with gas supply as the variable to achieve the specimen flux level as calibrated. This level should be monitored with use of either a radiation pyrometer fixed to view an area of the source surface or a fluxmeter mounted in a dummy specimen, as defined in paragraph 3.3 under "Definitions", at the 350 mm position. If the latter method is used, the assembly of dummy specimen and fluxmeter should remain in place between tests.

4.4 Adjustments and calibrations - general

The following adjustments and calibrations are to be achieved by burning methane gas from the line heat source located parallel to, and in the same plane as, the centreline of a dummy specimen located in position and without fluxmeters. This line burner comprises a 2 m length of pipe of 9.1 mm internal diameter. One end is closed off with a cap and a line of 15 holes of 3 mm diameter are drilled at 16 mm spacing through the pipe wall. The gas burned as it flows through this line of vertically positioned holes flames up through the stack. The measured flow rate and the net or lower heat of combustion of the gas serve to produce a known heat release rate which can be observed as a compensated stack millivolt signal change. Prior to performing calibration tests, measurements must be conducted to verify that the stack thermocouple compensation has been properly adjusted.

4.5 Compensation adjustment

The fraction of the signal from the compensator thermocouple which is subtracted from the stack thermocouple output should be adjusted by means of the resistance of one leg of the potential divider shown in figure 10. The purpose of this adjustment is as far as practical, to eliminate from the stack signal the long-term signal changes resulting from the relatively slow stack metal temperature variations. Figure 11 shows the curves resulting from under-compensation, correct compensation, and over-compensation. These curves were obtained by abruptly placing the lighted gas calibration burner adjacent to the hot end of a dummy specimen and then extinguishing it. For this adjustment, the calibration gas feed rate should be set to correspond to a heat rate of one kW. The compensator potential divider should be adjusted to yield curves that show a rapid rise to a steady state signal which is essentially constant over a 5 min period following the first minute of

transient signal rise. When the calibration burner is shut off, the signal should rapidly decrease and reach a steady state value within two minutes. Following this, there should be no long-term rise or fall of the signal. Experience has shown that between 40% and 50% of the compensation thermocouple signal should be included in the output signal to achieve this condition. When properly adjusted, a square thermal pulse of 7 kW should show not more than approximately 7% overshoot shortly after application of the calibration flame (see figure 11).

4.6 Fume stack calibration

With the adjustment described in 4.5 completed and a steady state base signal having been achieved, stack calibration should be carried out with the radiant panel operating at 50.5 kW/m^2 and the pilot burner not lit. The calibration of the stack millivolt signal rise should be made by introducing and removing the line burner, as described in 4.4. The flow rate of methane gas of at least 95% purity should be varied over the range of about $0.004 \text{ m}^3/\text{min}$ to $0.02 \text{ m}^3/\text{min}$ in sufficient increments to permit plotting the data in a well defined curve of stack compensated millivolt signal rise against the net or lower heat input rate. A similar calibration should be performed with the calibration burner located at the cool end of the specimen. The two curves should show agreement in indicated heat release rate within about 15%. A typical curve is shown in figure 12. The curve for the calibration burner at the hot end of the specimen should be the one used for reporting all heat release measurements. This completes the calibration and the test equipment is ready for use.

5 ASSEMBLY AND MECHANICAL ADJUSTMENT OF THE FLAMMABILITY TEST APPARATUS

The following instructions assume that parts of the flammability test apparatus have been made according to the drawings. The radiant panel subassembly has been completed with the exception of the support brackets and reverberatory screen. The equipment can be assembled to permit test of specimens of thickness up to 50 mm or 75 mm. Unless there is a real need for test of thicker specimens, assembly for 50 mm specimens is preferable.

5.1 The panel frame should be placed upright on a level floor, preferably in the location in which the equipment will be used.

5.2 The rotating ring should be mounted on its three guide bearings.

5.3 The panel mount frame should be bolted together, and to the ring, by four bolts.

5.4 A check should be made that the ring lies in a vertical plane. If the error is large, an adjustment of the upper ring support-bearing location may be necessary. Prior to making such an adjustment, it should be determined whether the error is due to excessive clearance between the ring and bearing rollers. If this is the case, rollers of larger diameter may correct the problem.

5.5 The four panel support brackets should be fastened to the radiant panel at four corners. Do not use too much force in bolting these brackets in place. Prior to mounting these brackets, one 35 mm M9 cap screw is placed in the hold that will be farthest from the panel end. These screws provide a means for mounting the panel.

5.6 Four washers should be placed on each of the panel mounting screws and the panel assembled on the mount bracket.

5.7 The angularity of the radiant panel surface with the plane of the mounting ring should be checked. This can be accomplished by means of a carpenter's square and measurements to the refractory tile surface at both ends of the panel. Any deviation from the required 15° angle may be adjusted by increasing or reducing the number of washers on the mounting screws.

5.8 The radiant panel should be rotated to face a specimen mounted in a vertical plane.

5.9 The panel surface should be checked with a level to ensure that it also lies in a vertical plane.

5.10 The specimen frame with specimen support rails on side and bottom positions and pilot burner holders assembled in approximate positions should be brought up to the burner frame and the two frames fastened together with two bolts and six nuts or two threaded rods and eight nuts. The spacing between the frames is roughly 100 mm.

5.11 The spacing of the two sides of the frames is adjusted to ensure that the specimen support frame longitudinal members are at a 15° angle to the radiant panel surface.

5.12 The single specimen holder side guide rail for vertical specimen orientation should be adjusted so that it is at the required 15° angle to the radiant panel surface.

5.13 An empty specimen holder should be slid into position on the rail and the position of the upper guide fork adjusted to ensure that when a specimen is inserted in the holder its surface will lie in a vertical plane.

5.14 The stop screw determining the axial position of the specimen holder should be adjusted to ensure that the axis of the pilot burner is 10 ± 2 mm from the closest exposed edge of the specimen. This adjustment should again be made by use of an empty specimen holder and substitution of a 6 mm steel rod of 250 mm length for the pilot burner ceramic tube. When viewed from the back of the specimen holder, the spacing between rod axis and the edge of the specimen retaining flange of the holder should be 10 ± 2 mm.

5.15 With the specimen holder still in place against the top screw, the spacing between the panel and specimen support frames should be adjusted to make dimension B, figure 6, equal to about 125 mm. This adjustment is made by means of the two screws fastening the frames together. In making this adjustment, it is important to make equal adjustments on each side to maintain the angular relationship called for in adjustments 5.11 and 5.12.

5.16 The nuts supporting the specimen holder side guide rail should be adjusted to ensure that dimension A, figure 6, is 125 ± 2 mm. Again, equal adjustments to the two mounting points are required. When doing this, a check should be made to ensure that the guide rail and edge of the specimen holder are in a horizontal plane. In making this adjustment, it is important to ensure that the 45 mm stack position dimension shown in figure 7 is maintained. Another way of adjustment to dimension A is through changes in the number of washers mentioned in 5.6.

5.17 If necessary, procedure 5.13 should be repeated.

5.18 The reverberatory screen should be mounted on the radiant panel. This must be done in such a manner that it is free to expand as it heats up during operation.

5.19 The viewing rake with 50 mm pins is mounted on an angle fastened to the specimen holder guide rail. Its position is adjusted so that pins are located at multiples of 50 mm distance from the closest end of the specimen exposed to the panel. It should be clamped in this position.

TABLE 1
CALIBRATION OF FLUX TO THE SPECIMEN

Typical flux incident on the specimen and specimen positions at which the calibration measurements are to be made. The flux at the 50 mm and 350 mm positions should be matched. Calibration data at other positions should agree with typical values within 10%.

Distance from exposed end of the specimen	Typical flux levels at the specimen	Calibration position to be used
0 mm	49.5 kW/m ²	
50	50.5	50.5 kW/m ²
100	49.5	
150	47.1	X
200	43.1	
250	37.8	X
300	30.9	
350	23.9	23.9
400	18.2	
450	13.2	X
500	9.2	
550	6.2	X
600	4.3	
650	3.1	X
700	2.2	
750	1.5	X

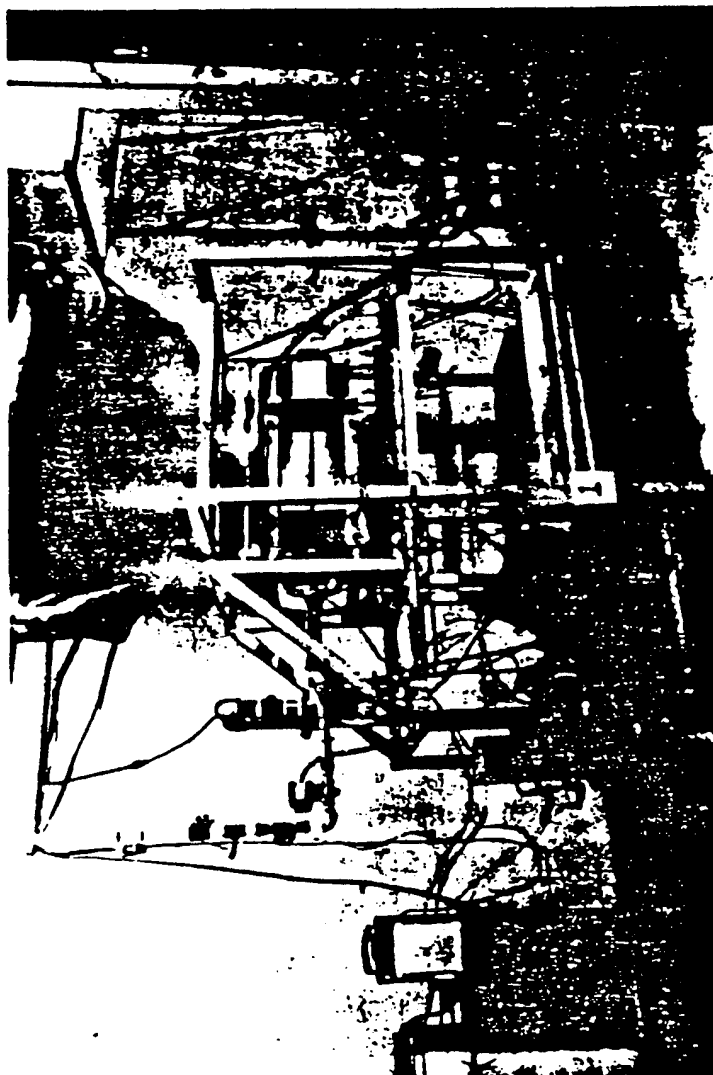


Figure 1 — General view of the apparatus



Figure 2 — View from specimen end

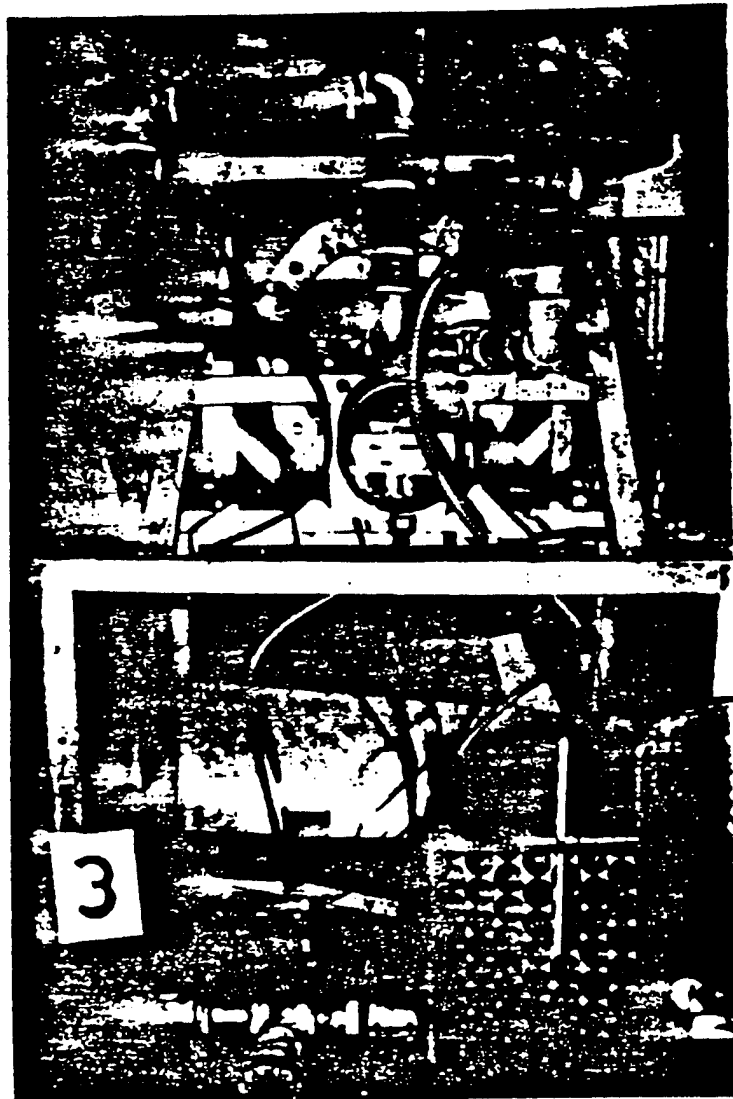


Figure 3 — View from radiant panel end

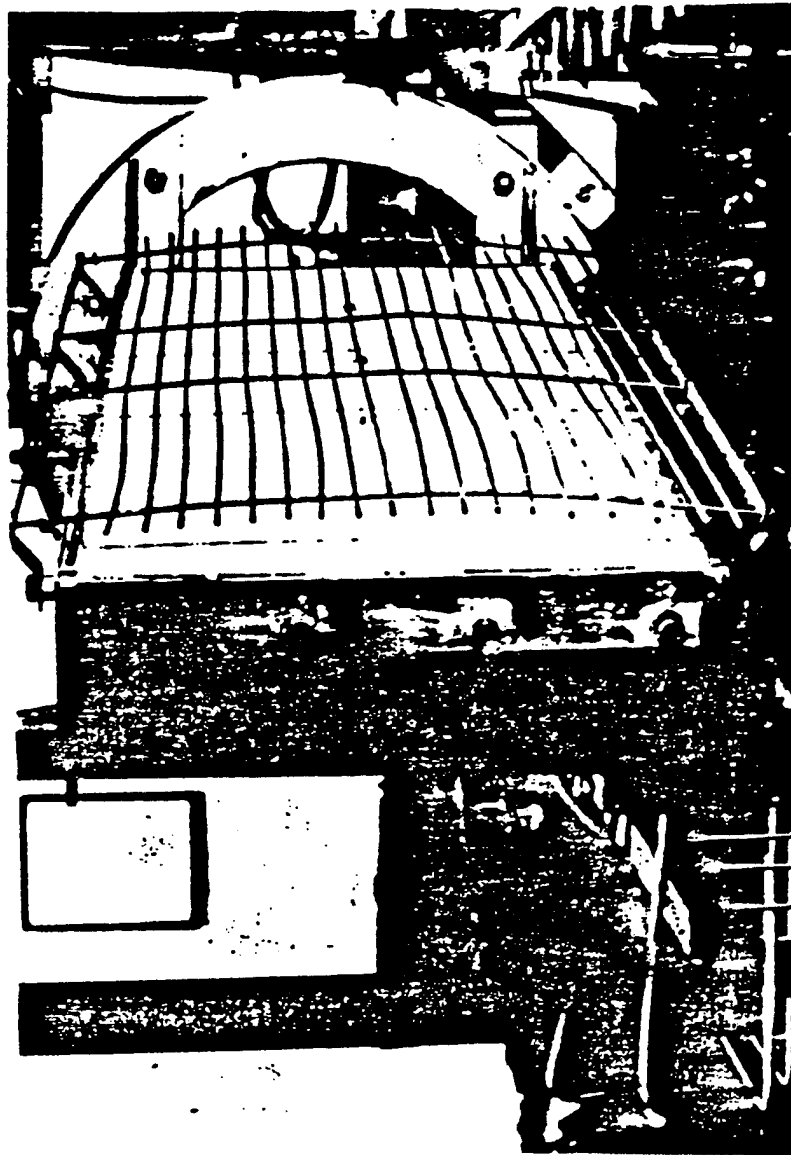


Figure 4 — *Radiant panel with reverberatory wires viewed through specimen mount frame*

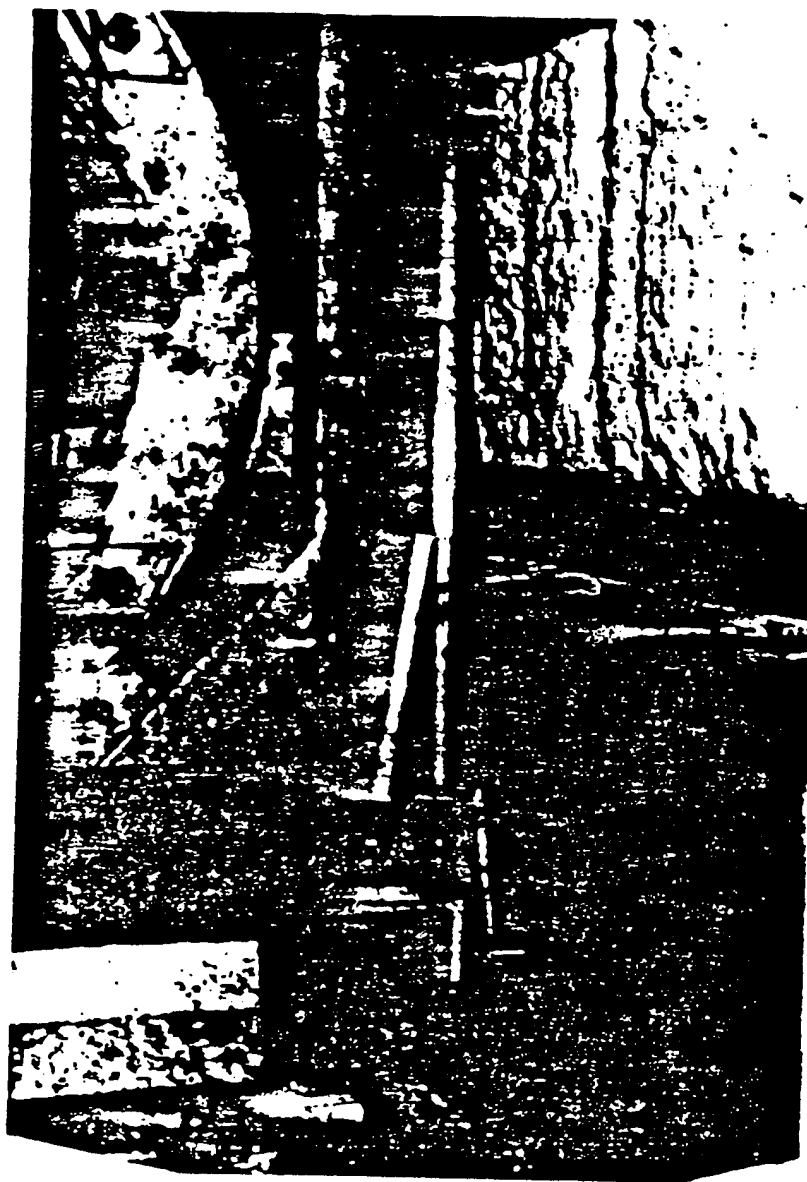
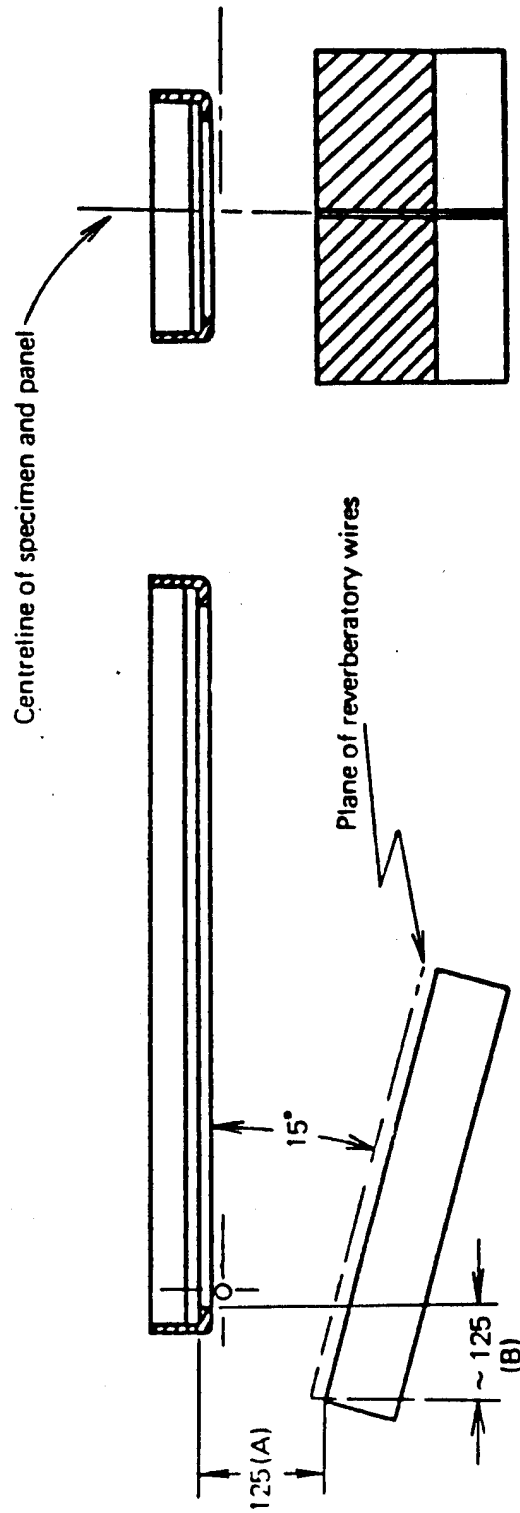


Figure 5 — *Pilot burner and mount*



C-34

Figure 6 - Specimen - panel arrangement

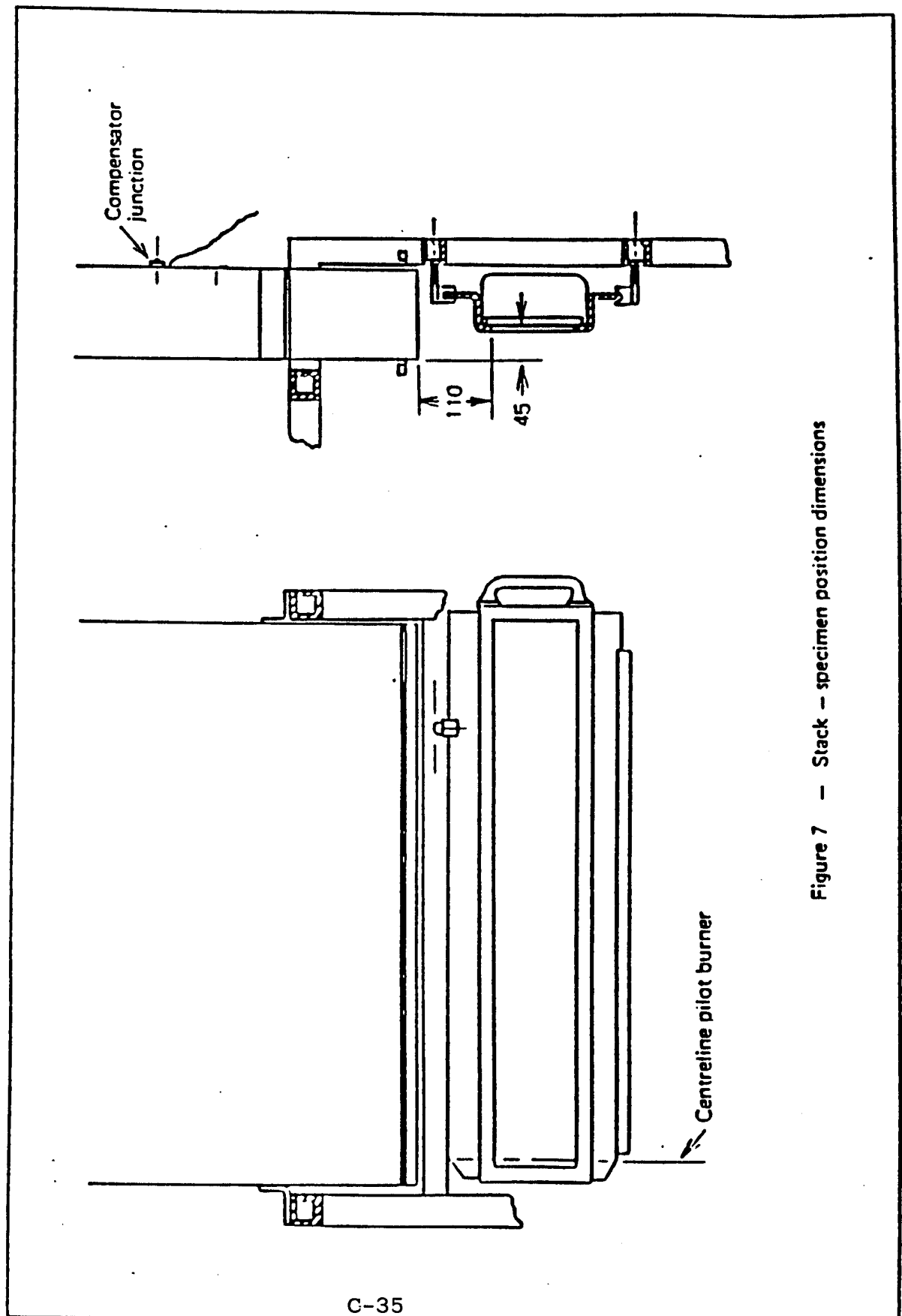


Figure 7 — Stack — specimen position dimensions

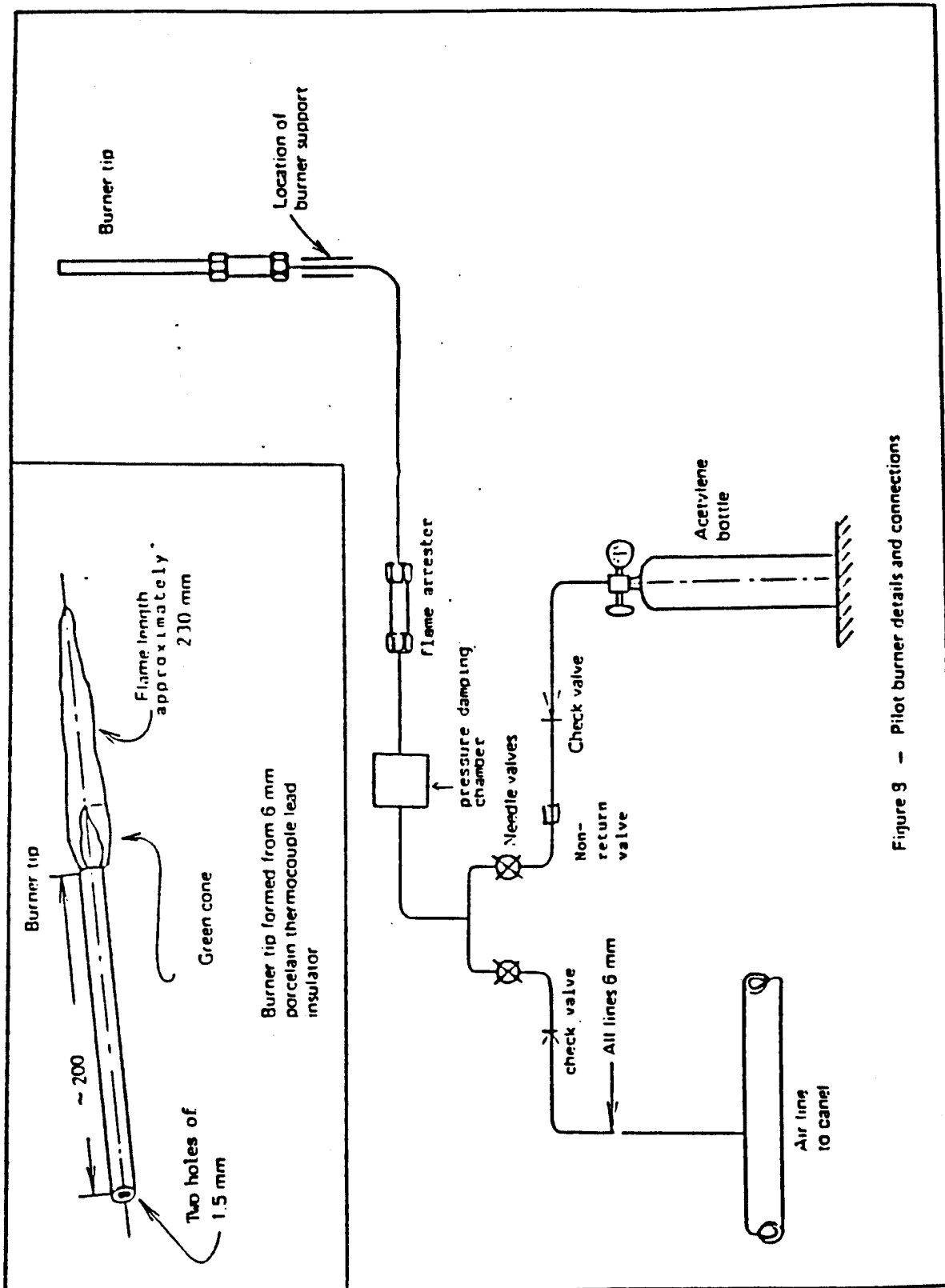


Figure 3 - Pilot burner details and connections

Figure 9 -- Position of pilot flame

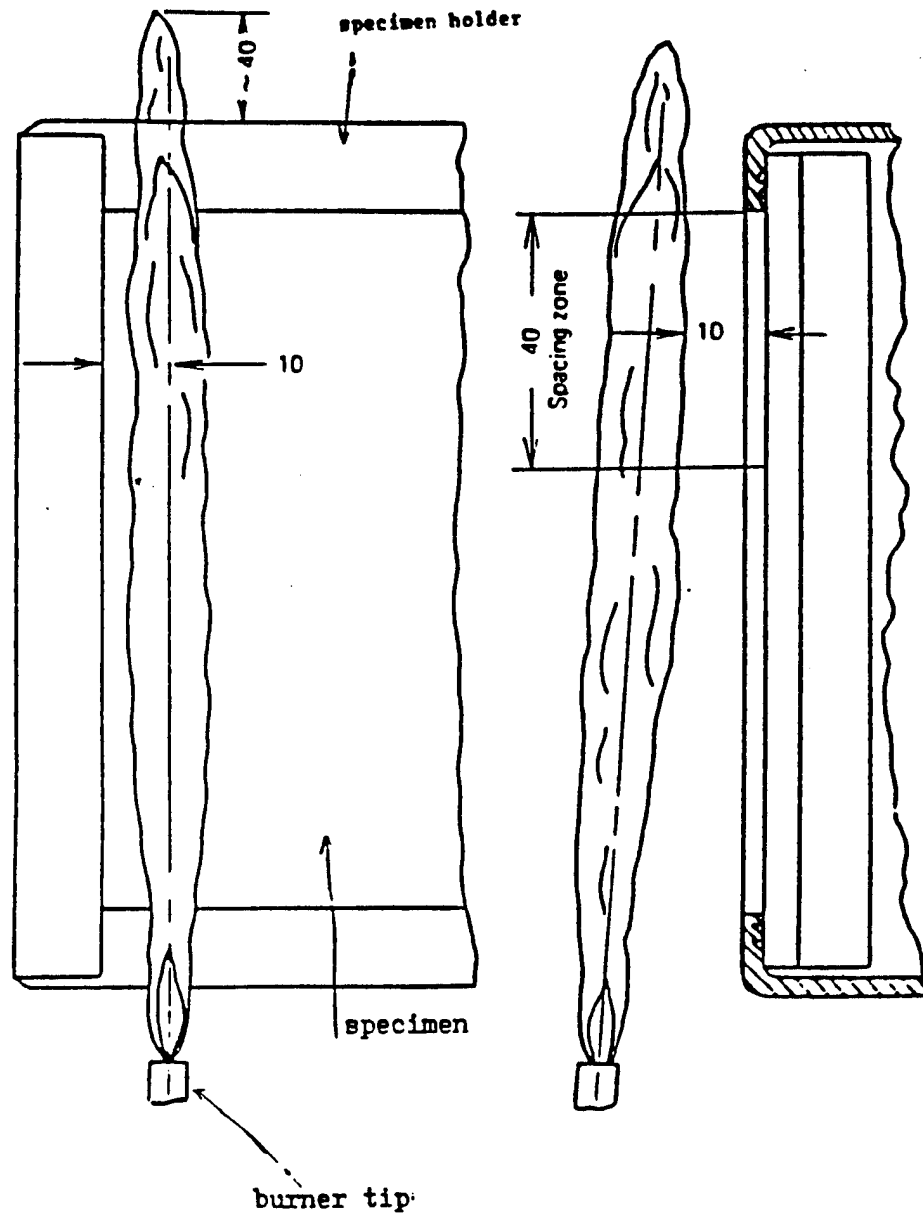


Figure 10 — Diagrammatic sketch of thermocouple circuit

Two sets of thermocouples and lead wires are required. The wire size and lengths within the fume T.C. group must be the same to ensure proper signal averaging. The parallel connection of the couples may be achieved at the mixing box by plug connection of the leads. This allows quick removal and checks for continuity and grounding problems with minimum delay. No cold junction should be used but the signal mixing box shall be shielded from panel radiation.

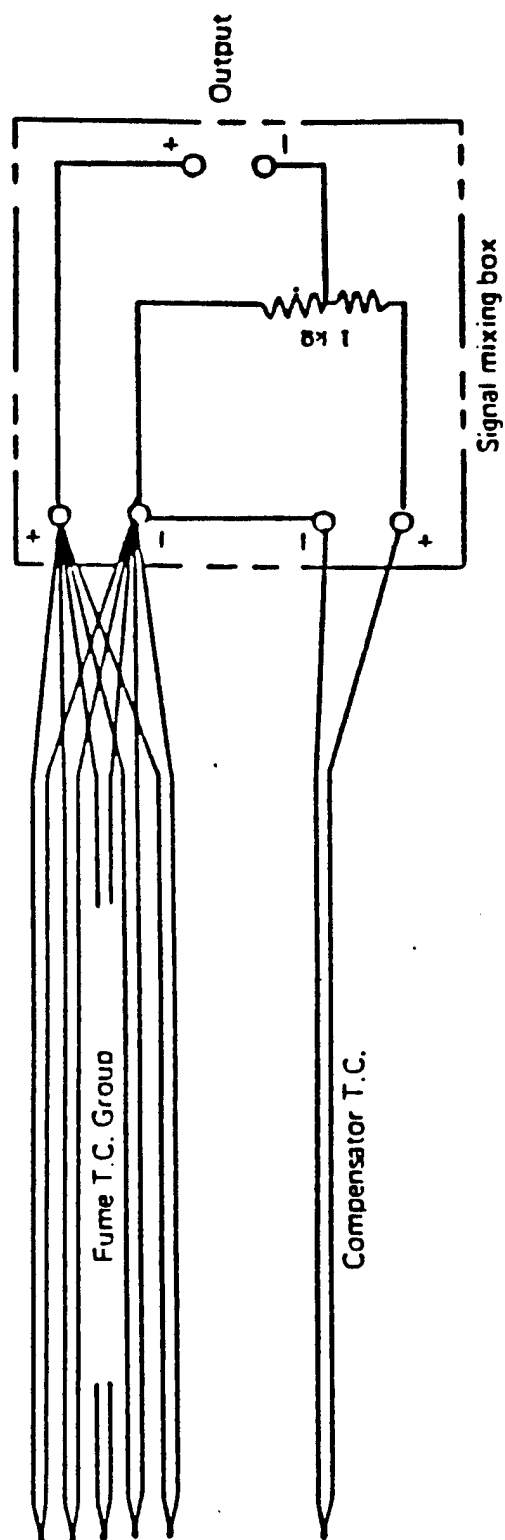
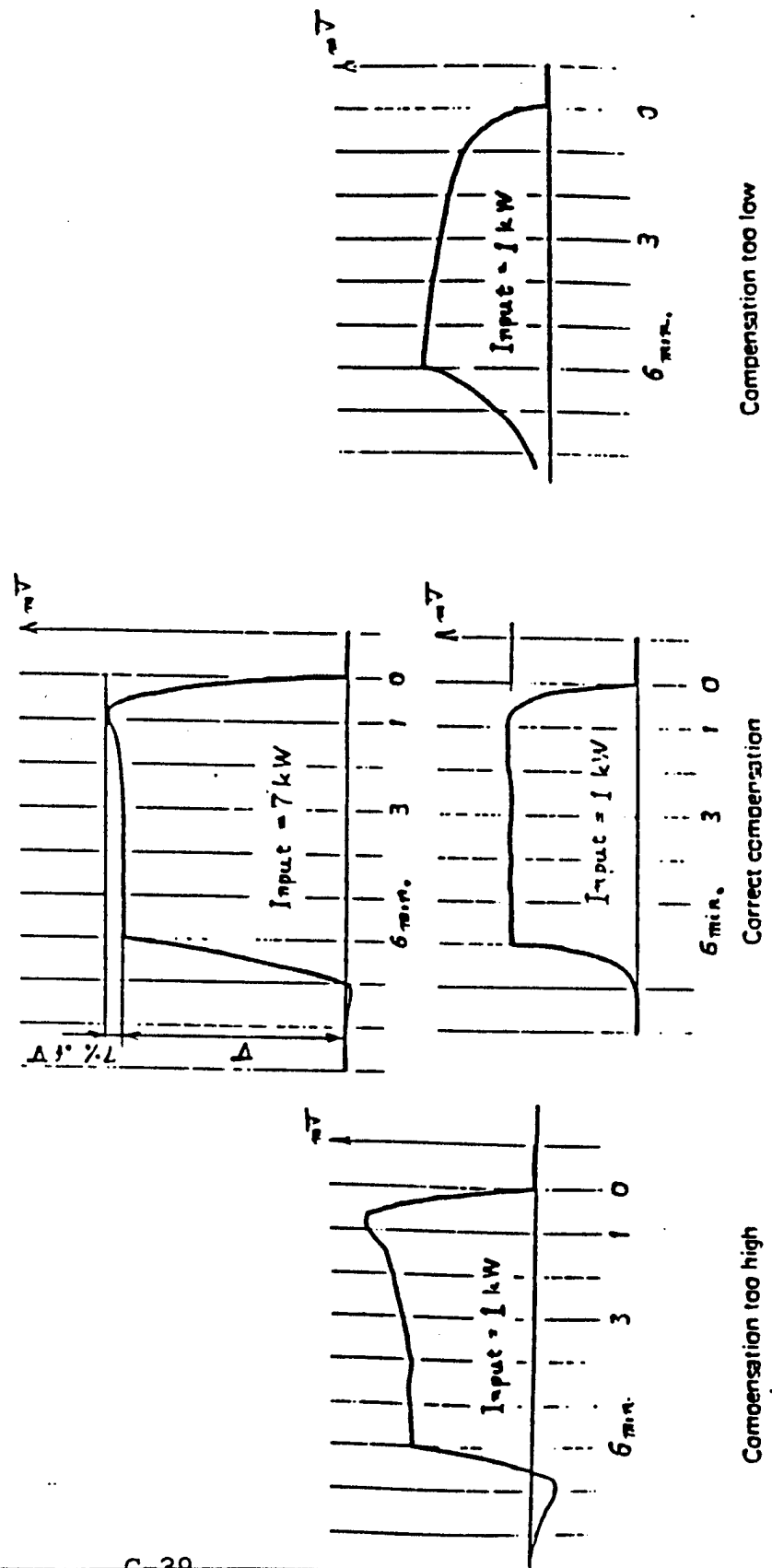


Figure 11 - Response behaviour of heat release signal to a square wave thermal pulse

The four curves shown illustrate changes in the indicated mV signal rise for three different levels of inverse feedback or compensation level.



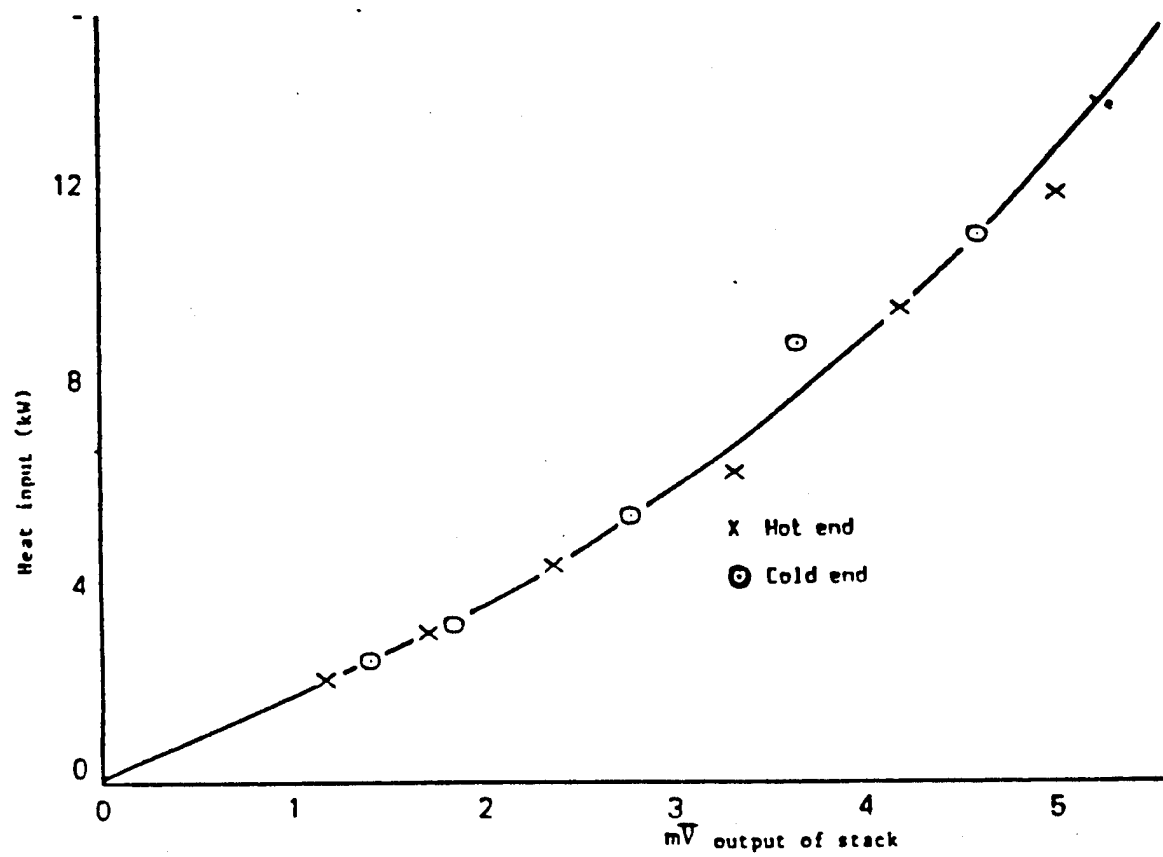


Figure 12 — Typical stack calibration

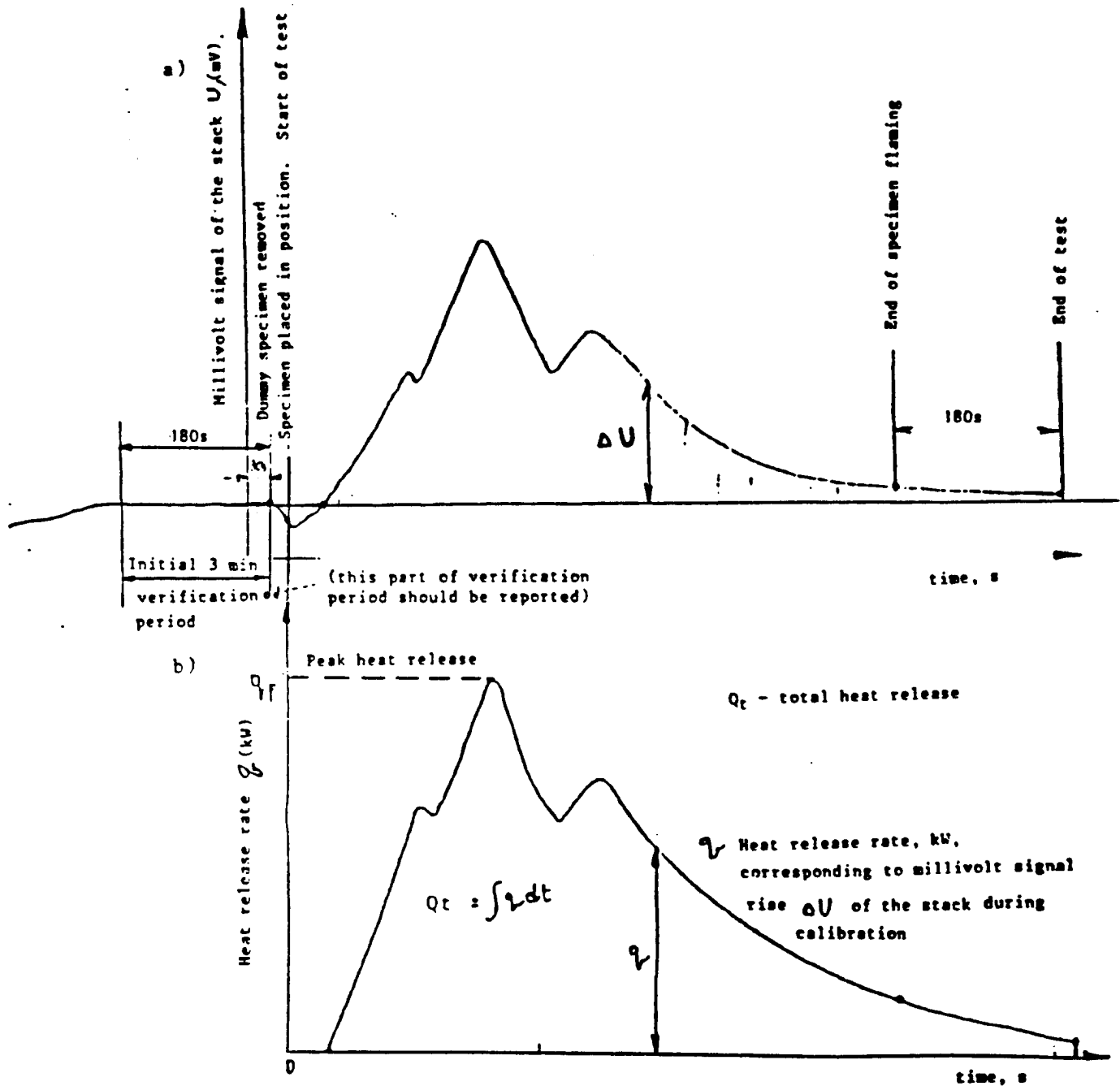
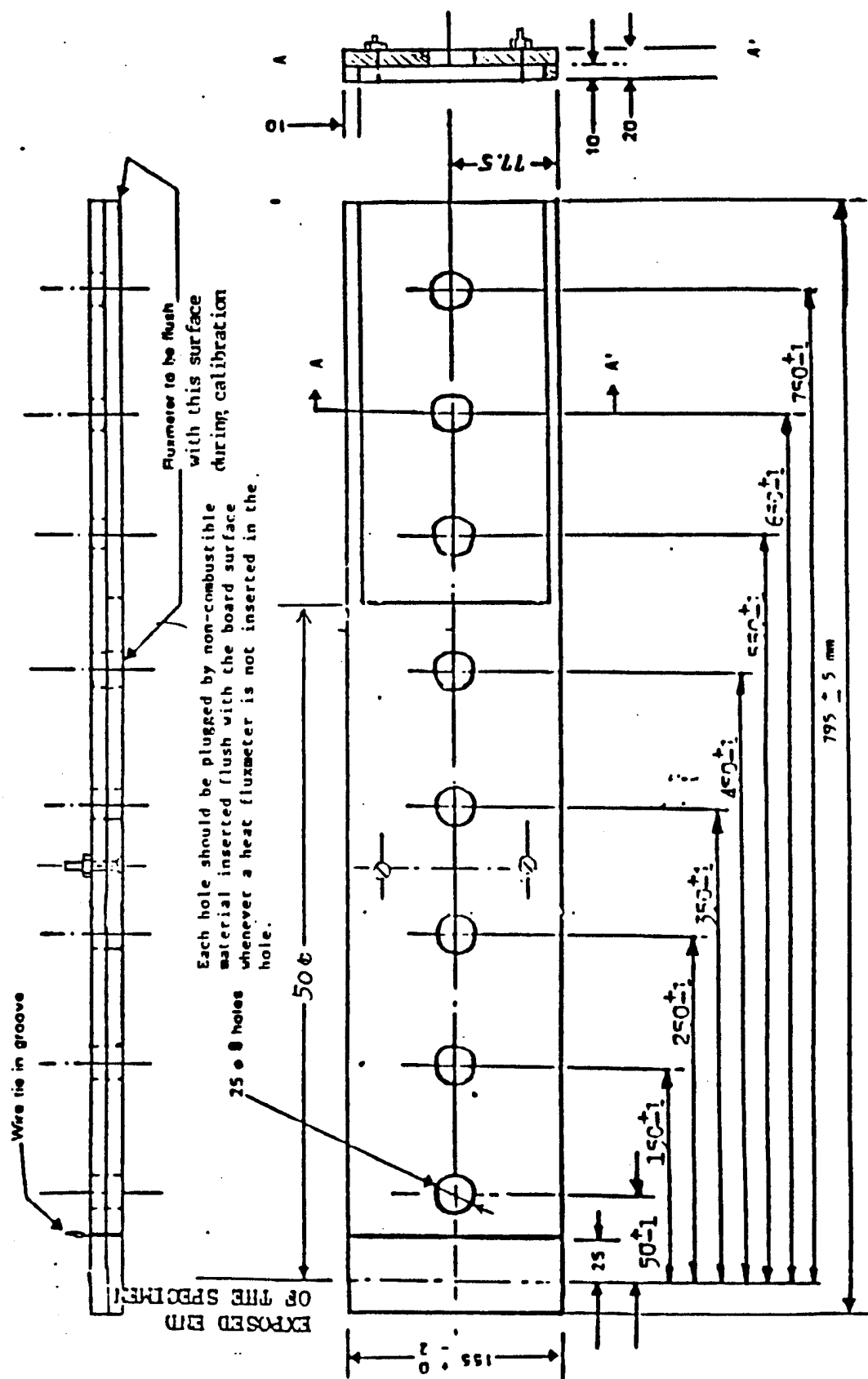


Figure 13

Conversion of the millivolt signal rise ΔU to heat release rate of the specimen:

- a - millivolt signal change recorded during test
- b - millivolt signal converted to heat release rate curve

Figure 14 -- Special calibration dummy specimen for flux gradient calibration



Appendix D

Test Method for Flame Spread of Plastic Piping

TEST METHOD FOR FLAME SPREAD OF PLASTIC PIPING

Flame spread of plastic piping should be determined by IMO resolution A.653(16) entitled "Recommendation on Improved Fire Test Procedures for Surface Flammability of Bulkhead, Ceiling, and Deck Finish Materials" with the following modifications.

- 1 Tests should be made for each pipe material and size.
- 2 The test sample should be fabricated by cutting pipes lengthwise into individual sections and then assembling the sections into a test sample as representative as possible of a flat surface. A test sample should consist of at least two sections. The test sample shall be 8005 mm long. All cuts should be made normal to the pipe wall.
- 3 The number of sections that must be assembled together to form a test sample should be that which corresponds to the nearest integral number of sections which should make a test sample with an equivalent linearized surface width between 155 mm and 180 mm. The surface width is defined as the measured sum of the outer circumference of the assembled pipe sections that are exposed to the flux from the radiant panel.
- 4 The assembled test sample should have no gaps between individual sections.
- 5 The assembled test sample should be constructed in such a way that the edges of two adjacent sections should coincide with the centerline of the test holder.
- 6 The individual test sections should be attached to the backing calcium silicate board using wire (No.18 recommended) inserted at 50 mm intervals through the board and tightened by twisting at the back.
- 7 The individual pipe sections should be mounted so that the highest point of the exposed surface is in the same plane as the exposed flat surface of a normal surface.
- 8 The space between the concave unexposed surface of the test sample and the surface of the calcium silicate backing board should be left void.
- 9 The void space between the top of the exposed test surface and the bottom edge of the sample holder frame should be filled with a high temperature insulating wool if the width of the pipe segments extend under the side edges of the sample holding frame.

Appendix E
Test Specimen Information

Report Code: EFF
Manufacturer: Ameron
Address: P. O. Box 801148, Houston, TX 77280
Phone: (713) 690-7777
Trade Name: 2000M
Material: Epoxy Fiberglass Pipe

Composition: Filament-wound fiberglass, reinforced epoxy
pipe with 0.02-inch (0.5mm) integral
resin-rich epoxy liner

Thermal Conductivity: 2.3 Btu•in/(h•ft²•°F)
0.33 W/(m•K)

Specific Gravity: 1.79

Flow Coefficient: 150 Hazen-Williams

Sizes Used:

Nominal Diameter:	2in	(50mm)	3in	(80mm)
Outside Diameter:				
Inside Diameter:	2.09in	(53.1mm)	3.22in	(81.8mm)
Wall Thickness:	0.16in	(4.1mm)	0.16in	(4.1mm)
Schedule:				

Report Code: EFG
Manufacturer: A.O. Smith Corp., Smith Fiberglass Products
Inc.
Address: 2700 West 65th Street, Little Rock,
Arkansas, 72209
Phone: (501) 568-4010
Trade Name: Green Thread
Material: Epoxy Fiberglass Pipe
Composition: Fiberglass reinforced epoxy resin pipe with
a glass mat reinforced epoxy resin liner
Thermal Conductivity: $2.8 \text{ BTU}/(\text{ft.}^2)(\text{hr.})(^\circ\text{F}/\text{in.})$
Specific Gravity: 1.8
Flow Coefficient: 150 Hazen-Williams

Sizes Used:

Nominal Diameter:	2in	3in	4in
Outside Diameter:	2.375in	3.5in	4.5in
Inside Diameter:	2.145in	3.27in	4.27in
Wall Thickness:	0.115in	0.115in	0.115in
Schedule:			

Report Code: PHE
Manufacturer: Ametek, HAVEG Division
Address: 900 Greenbank Road, Wilmington, DE 19808
Phone: (302) 995-0400
Trade Name: Chemtite SP
Material: Phenolic Pipe

Composition: Filament-wound, corrosion-resisant scilica
and filler with a proprietary corrosion
resistent phenolic resin binder

Thermal Conductivity: 2-3 Btu/hr, °F, ft²/in.

Specific Gravity: 1.75

Flow Coefficient: 145 Hazen-Williams

Sizes Used:

Nominal Diameter:	2in	4in	6in
Outside Diameter:	2.38in	4.50in	6.62in
Inside Diameter:	2.01in	3.99in	6.12in
Wall Thickness:	0.18in	0.25in	0.25in
Schedule:			

Report Code: VEF
Manufacturer: Ameron
Address: P. O.Box 801148, Houston, TX 77280
Phone: (713) 690-7777
Trade Name: 5000M
Material: Vinylester Fiberglass Pipe

Composition: Filament-wound fiberglass reinforced
vinylester pipe with integral 0.05-inch
(1.3mm) resin-rich reinforced liner and
0.25-inch (6mm) closed-cell foam
external coating

Thermal Conductivity 2.0 Btu •in/(hr •ft²•°F)
of Pipe Wall: 0.28 W/m •K
of 0.2 Btu •in/hr •ft²•°F)
Protective Coating: 0.028 W/m •K

Specific Gravity: 1.8

Flow Coefficient: 150 Hazen Williams

Sizes Used:

Nominal Diameter:	2in (50mm)	4in (100mm)
Outside Diameter:		
Inside Diameter:	2.10in (53mm)	4.14in (105mm)
Wall Thickness:	0.157in (4mm)	0.203in (5.2mm)
Schedule:		

Report Code: VEG
Manufacturer: A.O. Smith Corp., Smith Fiberglass Products
Inc.
Address: 2700 West 65th Street, Little Rock,
Arkansas 72209
Phone: (501) 568-4010
Trade Name: Poly Thread
Material: Vinylester Fiberglass Pipe

Composition: Fiberglass reinforced vinyl ester resin
pipe with a glass mat reinforced vinyl
ester resin liner for use in corrosive
services

Thermal Conductivity: $1.3 \text{ BTU}/(\text{ft.}^2)(\text{hr.})(^\circ\text{F}/\text{in.})$

Specific Gravity: 1.85

Flow Coefficient:

Sizes Used:

Nominal Diameter: 2in
Outside Diameter: 2.375in
Inside Diameter: 2.135in
Wall Thickness: 0.12in
Schedule:

Report Code: PVA
Manufacturer: Charlotte Pipe & Foundry Company, Plastics
Division
Address: P. O. Box 35430, Charlotte, NC 28235
Phone: (704) 372-5030
Trade Name: -----
Material: Polyvinyl Chloride Pipe

Composition: Polyvinyl Chloride

Thermal Conductivity:

Specific Gravity:

Flow Coefficient:

Sizes Used:

Nominal Diameter:	2in	4in	6in
Outside Diameter:	2.375in	4.5in	6.625in
Inside Diameter:			
Wall Thickness:	0.154in	0.237in	0.28in
Schedule:	40	40	40

Report Code: CPB
Manufacturer: Spears Manufacturing Co.
Address: 15853 Olden Street / P. O. Box 4428, Sylmar
CA 91342-0428
Phone: (818) 364-1611
Trade Name: BlazeMaster
Material: Chlorinated Polyvinyl Chloride Pipe

Composition: Chlorinated Polyvinyl Chloride

Thermal Conductivity: 0.95 BTU/(hr°F ft/in²)

Specific Gravity: 1.55

Flow Coefficient: 150 Hazen-Williams

Sizes Used:

Nominal Diameter: 2in
Outside Diameter: 2.375in (60.3mm)
Inside Diameter: 2.003in (50.9mm)
Wall Thickness:
Schedule:

Report Code: CPC
Manufacturer: Thompson Plastics Inc.
Address: P. O. Box 17133, 3425 Stanwood Boulevard NE
Huntsville, AL 35810
Phone: (205) 859-1600
Trade Name: Flowguard (now called Flowguard Gold)
Material: Chlorinated Polyvinyl Chloride Pipe

Composition: Chlorinated Polyvinyl Chloride

Thermal Conductivity: 1.0 Btu/hr - SF -°F/in

Specific Gravity: 1.55

Flow Coefficient: 150 Hazen-Williams

Sizes Used:

Nominal Diameter: 2in
Outside Diameter: 2.125in
Inside Diameter: 1.739in
Wall Thickness: 0.193in
Schedule:

Report Code: CPD
Manufacturer: Harvel Plastics
Address: P. O. Box 757-T, Kuebler Road, Easton, PA
18044-0757
Phone: (610) 252-7391
Trade Name: -----
Material: Chlorinated Polyvinyl Chloride Pipe
Composition: Chlorinated Polyvinyl Chloride

Thermal Conductivity: $0.96 \frac{(\text{Cal.})(\text{cm})}{(\text{cm}^2)(\text{sec.})(^\circ\text{C})} \times 10^4$

Specific Gravity: 1.55 ±.02

Flow Coefficient: 150 Hazen-Williams

Sizes Used:

Nominal Diameter: 2in
Outside Diameter: 2.375in
Inside Diameter:
Wall Thickness: (6mm)
Schedule:

Appendix F
IEC 332-3 Test Data

Appendix F

Test No.	Pipe Description	Pipe Diameter (inches)	Distance Between Pipes(mm)	Char Height (up to m)	IEC 332-3 Test Results (performance requirement)
EPOXY PIPES					
21	EFF2	2	25	2.06	Pass
1	EFF2	2	51	1.73	Pass
2	EFF3	3	25	2.69	Fail
22	EFF3	3	51	2.06	Pass
41	EFF3	3	76	1.70	Pass
3a	EFF4	4	--	0.84	Pass
3	EFF4	4	51	3.05	Fail
23	EFF4	4	51	3.05	Fail
4	EFF6	6	51	3.05	Fail
24	EFF6	6	51	3.05	Fail
5a	EFF8	8	--	0.81	Fail
46	EFG2	2	--	0.28	Pass
25	EFG2	2	25	1.60	Pass
5	EFG2	2	51	0.71	Pass
6	EFG3	3	25	2.82	Fail
26	EFG3	3	51	1.78	Pass
42	EFG3	3	76	1.63	Pass
4a	EFG4	4	--	0.53	Pass
7	EFG4	4	51	1.88	Pass
27	EFG4	4	51	1.55	Pass
45	EFG6	6	--	0.84	Pass
8	EFG6	6	51	3.05	Fail
28	EFG6	6	51	3.05	Fail
6a	EFG8	8	--	0.76	Pass

Appendix F (continued)

Test No.	Pipe Description	Pipe Diameter (inches) (Nominal)	Distance Between Pipes(mm)	Char Height (up to m)	IEC 332-3 Test Results (performance requirement) of charring less than 2.5 m
=====					
VINYLESTER PIPES					
9	VEF2	2	51	1.12	Pass
29	VEF2	2	51	0.86	Pass
10	VEF4	4	25	3.05	Fail
30	VEF4	4	51	1.60	Pass
43	VEF4	4	76	1.19	Pass
11	VEF6	6	51	3.05	Fail
31	VEF6	6	51	3.05	Fail
=====					
32	VEG2	2	25	2.44	Pass
12	VEG2	2	51	2.01	Pass
13	VEG4	4	25	3.05	Fail
33	VEG4	4	51	3.05	Fail
44	VEG4	4	76	3.05	Fail
14	VEG6	6	51	3.05	Fail
34	VEG6	6	51	3.05	Fail
=====					
POLYVINYL CHLORIDE PIPES					
9a	PVA2	2	25	0.61	Pass
18	PVA2	2	51	0.71	Pass
38	PVA2	2	51	0.74	Pass
10a	PVA4	4	25	1.30	Pass
39	PVA4	4	51	1.42	Pass
19	PVA4	4	51	1.04	Pass
20	PVA6	6	51	1.30	Pass
40	PVA6	6	51	1.02	(collapsed to floor)

Appendix F (continued)

Test No.	Pipe Description	Pipe Diameter (inches)	Distance Between Pipes(mm)	Char Height (up to m)	IEC 332-3 Test Results (performance requirement)
=====					
PHENOLIC PIPES					
14a	PHE2	2	--	0.20	Pass
15	PHE2	2	51	0.25	Pass
35	PHE2	2	51	0.38	Pass
15a	PHE4	4	--	0.20	Pass
16	PHE4	4	51	0.31	Pass
36	PHE4	4	51	0.43	Pass
17	PHE6	6	51	0.48	Pass
37	PHE6	6	51	0.43	Pass
=====					

Appendix G

IEC 332-3 Data Corrected for Geometry

Appendix G
IEC 332-3 Data Corrected for Geometry

Test No.	Pipe Description	Pipe Diameter (mm)	Distance Between Pipes (mm)	Char Height (up to m)	View Factor	Corrected Char Height	Percent Difference
=====							
EPOXY PIPES							
21	EFF2	60.325	25.000	2.060	0.118	1.426	17.596
1	EFF2	60.325	51.000	1.730	0.089	1.741	-0.634
2	EFF3	88.900	25.000	2.690	0.132	1.609	7.005
22	EFF3	88.900	51.000	2.060	0.105	1.661	4.010
41	EFF3	88.900	76.000	1.700	0.088	1.723	0.413
			AVG 2/2	1.730			
=====							
25	EFG2	60.325	25.000	1.600	0.118	1.545	9.909
5	EFG2	60.325	51.000	0.710	0.089	0.997	41.865
6	EFG3	88.900	25.000	2.820	0.132	2.353	-37.227
26	EFG3	88.900	51.000	1.780	0.105	2.002	-16.751
42	EFG3	88.900	76.000	1.630	0.088	2.305	-34.408
7	EFG4	114.300	51.000	1.880	0.115	1.875	-9.313
27	EFG4	114.300	51.000	1.550	0.115	1.546	9.875
			AVG 4/2	1.715			
=====							
VINYLESTER PIPES							
9	VEF2	60.325	51.000	1.120	0.089	1.127	-13.848
29	VEF2	60.325	51.000	0.860	0.089	0.865	12.581
30	VEF4	114.300	51.000	1.600	0.115	1.143	-15.495
43	VEF4	114.300	76.000	1.190	0.099	1.038	-4.882
			AVG 2/2	0.990			
=====							
32	VEG2	60.325	25.000	2.440	0.118	1.689	15.992
12	VEG2	60.325	51.000	2.010	0.089	2.023	-0.634
			AVG 2/2	2.010			

Appendix G (continued)
IEC 332-3 Data Corrected for Geometry

Test No.	Pipe Description	Pipe Diameter (mm)	Distance Between Pipes (mm)	Char Height (up to m)	View Factor	Corrected Char Height	Percent Difference
POLYVINYL CHLORIDE PIPES							
18	PVA2	60.325	51.000	0.710	0.089	0.714	1.448
38	PVA2	60.325	51.000	0.740	0.089	0.745	-2.716
39	PVA4	114.300	51.000	1.420	0.115	1.015	-39.968
19	PVA4	114.300	51.000	1.040	0.115	0.743	-2.512
20	PVA6	168.275	51.000	1.300	0.130	0.797	-9.994
40	PVA6	168.275	51.000	1.020	0.130	0.626	13.697
			AVG 2/2	0.725			
PHENOLIC PIPES							
15	PHE2	60.325	51.000	0.250	0.089	0.252	20.132
35	PHE2	60.325	51.000	0.380	0.089	0.382	-21.399
16	PHE4	114.300	51.000	0.310	0.115	0.222	29.672
36	PHE4	114.300	51.000	0.430	0.115	0.307	2.448
17	PHE6	168.275	51.000	0.480	0.130	0.294	6.525
37	PHE6	168.275	51.000	0.430	0.130	0.264	16.262
			AVG 2/2	0.315			
							AVG or MEAN
							STD DEV
							k
							1.3

Appendix H

IMO Resolution A.653(16) Data

Appendix H

IMO Resolution A.653(16) Data

Material Code	Test No.	Diameter/Segments	Linear Surface (mm)	Wall Thickness (mm)	Panel Flux kw/m2	Qt MJ	qp kw	Qsb MJ	CFE kw/m2	Qign MJ	Mass Loss
EFF	46/1	D4S4/2	177	5 mm	50.7	0.97	3.8	5.1	10.1	4.4	201
EFF	47/1	D4S4/2	170	5 mm	50.9	1.14	4.0	5.3	4.9	4.4	208
EFF	48/1	D4S4/2	178	5 mm	50.9	1.02	4.1	5.1	7.0	4.2	191
EFF	43/1	D6S6/2	162	5 mm	51.3	1.29	5.0	3.6	10.9	4.1	212
EFF	44/1	D6S6/2	160	5 mm	51.1	1.16	4.5	4.6	10.9	4.0	171
EFF	45/1	D6S6/2	159	5 mm	51.2	1.30	4.8	3.9	4.1	4.5	211
EFG	62/1	D4S4/2	172	3 mm	50.7	0.72	5.9	5.6	9.7	4.0	145
EFG	63/1	D4S4/2	165	3 mm	50.6	---	---	4.3	17.9	4.0	124
EFG	64/1	D4S4/2	165	3 mm	50.7	0.60	4.4	5.1	18.5	3.8	122
EFG	65/1	D4S4/2	170	3 mm	50.9	0.55	4.4	6.4	14.6	3.8	151
PHE	24/1	D2S2/2	188	6 mm	50.8	0.57	1.3	26.2	25.2	28.8	214
PHE	27/1	D2S2/2	194	6 mm	50.6	0.78	1.4	17.2	27.8	22.2	223
PHE	38/1	D2S2/2	186	6 mm	50.6	0.46	0.9	16.9	20.8	21.5	165
PHE	23/1	D4S4/2	172		51.0	0.63	1.4	19.6	25.8	24.9	210
PHE	26/1	D4S4/2	179		50.6	0.65	1.3	19.8	27.1	24.3	202
PHE	39/1	D4S4/2	172		50.7	0.47	0.9	17.9	22.1	19.4	187
PHE	25/1	D6S6/2	154	7 mm	50.6	0.57	1.4	19.5	25.8	27.7	214
PHE	32/1	D6S6/2	154	7 mm	50.6	0.51	1.0	25.3	23.3	37.4	172
PHE	40/1	D6S6/2	159	7 mm	50.7	0.51	1.1	18.4	23.3	22.4	170
VEF	52/1	D4S4/2	161	5 mm	50.7	0.87	3.3	4.8	8.9	4.3	220
VEF	53/1	D4S4/2	163	5 mm	50.4	0.80	2.9	4.9	10.1	4.4	184
VEF	54/1	D4S4/2	162	5 mm	50.3	1.12	2.7	4.7	3.7	4.5	257
VEF	49/1	D6S6/2	161	5 mm	51.1	1.30	3.0	3.8	1.3	4.0	222
VEF	50/1	D6S6/2	160	5 mm	50.6	1.21	3.2	4.6	7.0	4.0	205
VEF	51/1	D6S6/2	151	5 mm	51.1	0.87	2.6	4.3	5.1	3.8	208

Appendix H (continued)

IMO Resolution A.653(16) Data

Material Code	Test No.	Diameter/ Segments	Linear Surface (mm)	Wall Thickness (mm)	Panel Flux kw/m2	Qt MJ	qp kw	Qsb MJ	CFE kw/m2	Qign MJ	Mass Loss
VEG	59/1	D4S4/2	172	4 mm	50.7	1.52	4.7	4.3	5.3	4.2	187
VEG	60/1	D4S4/2	174	4 mm	50.8	1.24	4.8	4.5	4.7	4.7	187
VEG	61/1	D4S4/2	171	4 mm	50.6	1.19	4.8	4.5	4.6	4.4	181
VEG	56/1	D6S6/2	159	4 mm	50.7	0.80	5.9	7.1	4.4	4.7	167
VEG	57/1	D6S6/2	163	4 mm	50.9	1.00	4.4	4.5	4.6	4.6	176
VEG	58/1	D6S6/2	152	4 mm	51.3	1.04	3.9	4.4	1.3	4.4	170
PVA	20/1	D.75S2/1	39	3 mm	50.7	0.05	0.1	---	---	---	122
PVA	21/1	D.75S2/2	39 40*	3 mm	50.5	0.35	0.4	---	---	---	186
PVA	22/1	D.75S2/2	39 40!	3 mm	51.0	0.31	0.4	---	---	---	178
PVA	7/1	D.75S2/4	160	3 mm	50.5	0.52	1.5	11.7	36.0	6.6	292
PVA	4/1	D.75S2/5	200	3 mm	50.4	0.59	2.4	4.7	21.5	6.0	327
PVA	5/1	D.75S1/4	335	3 mm	50.5	1.12	2.0	11.6	24.6	6.7	282
PVA	6/1	D.75S1/5	411	3 mm	50.6	1.13	2.1	8.3	21.5	8.9	704?
PVA	8/1	D2S2/2	180	4 mm	50.5	0.88	1.7	8.2	30.1	5.7	363
PVA	14/1	D2S2/2	180	4 mm	50.7	0.80	0.9	6.3	20.8	6.2	375
PVA	37/1	D2S2/2	179	4 mm	50.8	0.90	1.2	8.8	20.8	7.3	349
PVA	9/1	D4S4/2	183	6 mm	50.0	0.94	1.8	10.5	21.4	7.2	490
PVA	13/1	D4S4/2	172	6 mm	50.6	1.03	1.6	4.5	26.5	6.2	518
PVA	36/1	D4S4/2	168	6 mm	51.2	1.33	2.0	8.8	21.4	9.5	489
PVA	18/1	D4S4/1	90	6 mm	50.3	0.73	1.0	8.2	21.5	6.6	288
PVA	12/1	D4S6/2	163	6 mm	50.7	1.38	2.1	7.5	18.5	7.0	927?
PVA	19/1	D4S6/2	112	6 mm	50.6	0.80	1.3	11.2	22.7	6.6	391
PVA	11/1	D6S6/2	162	8 mm	50.5	1.24	1.9	9.5	27.8	13.3	560
PVA	34/1	D6S6/2	152	8 mm	50.1	1.32	2.0	8.0	25.8	11.1	490
PVA	35/1	D6S6/2	159	8 mm	50.7	1.36	1.9	8.3	25.8	10.6	588
PVA	10/1	D6S9/3	159	8 mm	50.6	1.27	1.8	10.6	21.5	12.2	533
PVA	1/2	D2S2/2	190	4 mm	50.8	0.95	1.3	7.3	22.3	7.3	290
PVA	2/2	D2S2/2	188	4 mm	50.6	1.22	1.5	7.5	18.6	7.2	305
PVA	4/2	D2S2/2	189	4 mm	50.5	1.02	1.0	7.7	15.0	7.1	286

Appendix H (continued)

IMO Resolution A.653(16) Data

Material Code	Test No.	Diameter/Segments	Linear Surface (mm)	Wall Thickness (mm)	Panel Flux kw/m2	Qt MJ	qp kw	Qsb MJ	CFE kw/m2	Qign MJ	Mass Loss
CPB	3/2	D2S2/2	190	5 mm	50.5	0.82	0.8	32.0	11.4	40.0	513
CPB	7/2	D2S2/2	189	5 mm	51.3	1.06	1.1	---	---	---	326
CPB	8/2	D2S2/2	189	5 mm	50.7	0.71	0.7	30.0	8.4	37.0	428
CPB	12/2	D2S2/2	190	5 mm	50.9	0.52	0.5	37.0	17.6	42.0	443
CPC	5/2	D2S2/2	189	5 mm	50.0	0.67	0.7	40.0	40.0	46.0	453
CPC	9/2	D2S2/2	170	5 mm	50.8	0.52	0.7	34.0	15.0	51.0	431
CPC	13/2	D2S2/2	169	5 mm	51.3	0.56	0.7	38.0	26.0	44.0	474
CPC	14/2	D2S2/2	170	5 mm	50.3	0.75	0.8	45.0	36.5	39.0	471
CPD	6/2	D2S2/2	189	6 mm	49.8	0.61	0.7	60.0	36.4	61.0	582
CPD	10/2	D2S2/2	190	6 mm	49.9	0.38	0.6	50.0	33.2	59.0	507
CPD	11/2	D2S2/2	189	6 mm	50.2	0.55	0.8	45.0	29.7	43.0	537
CPD	15/2	D2S2/2	188	6 mm	50.5	0.55	0.6	40.0	29.7	41.0	493

* = 2 Pipe Segments, Separated By A 10 mm Gap
 ! = 2 Pipe Segments, Separated By A 15 mm Gap
 ? = Weight Loss Data Suspect